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UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH ADMINISTRATION
BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

Project Date March 27, 1951 Author

SUBJECT—

TITLE

AN INVESTIGATION OF JEFFREY PINE MORTALITY IN THE LAGUNA RECREATION AREA

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U. S. GOVERNMENT PRINTING OFFICE 16—47272-1

AN INVESTIGATION OF JEFFREY PINE MORTALITY

IN THE LAGUNA RECREATION AREA

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AN INVESTIGATION OF JEFFREY PINE MORTALITY IN THE LAGUNA RECREATION AREA

INTRODUCTION

This paper presents the results of the work of the 1950 season on a study of Jeffrey pine in the Laguna Recreation Area of the Cleveland National Forest. The mortality of this species has been a major problem in this area for a long time, and this study was undertaken in an attempt to determine: (1) the agents responsible for the decline and decadence of these trees, (2) the nature of their action on the host, and (3) the various responses of the host to such agents. The results of the study, which are presented in the discussion that follows, have not given the complete answer to these three problems; however, they may contribute to a better understanding of the interactions of trees and their insect enemies.

The justification for this study is apparent when one considers that this timber stand now provides one of the most valuable and readily accessible forest recreation areas for San Diego and Imperial County residents. It is impossible to place a monetary value on the losses in this area. However, it is obvious that the recreation and watershed values resulting from the maintenance of this stand are such that they warranted an investigation of the causes of the unusually high rate of mortality which is occuring in the area.

An analysis of the conditions of infestation in other critical southern California areas has shown that the type of infestation described in this paper is unique to the area studied; however, this does not mean that the results reported herein have only a limited application. The Jeffrey pine stands of this region merely are under the influence of extreme environmental conditions which greatly accelerate the rates of reaction to given conditions, and it is probable that the results of these studies can be applied to similar problems involving different insect and host species.

The study, itself, was conducted in cooperation with a study of the biological agents associated with tree mortality and the external tree characters indicative of the presence of these agents. The results of this latter study are presented by Cox (1951) in a separate report and they only will be incorporated in this report insofar as they contribute to the understanding of the conditions of the host.

In general, the procedure followed in conducting the investigation involved: (1) an analysis of the green stand to determine the extent and nature of the annual mortality, (2) an analysis of many of the dead and dying trees to determine, if possible, the agents causing these conditions and the manner in which they worked, and (3) an analysis of the responses of the host to climatic and biotic factors which comprised its environment.

Infestation Studies

This stand of timber is unique in comparison with most of the timbered regions in southern California, in that it primarily is composed of immature Jeffrey pine with only a few scattered overmature trees. The losses in this area are concentrated chiefly in the immature trees in contrast to the conditions in most other areas where the greatest insect mortality occurs in the older overmature trees.

Green Stand Analysis

After a superficial examination had been made of the area, a partial cruise was made of the areas in which the investigations were to be made to establish the degree of infestation, and the mortality in the green stand. This cruise consisted of 1.75 miles of strip two chains wide which gave a total of 28 acres sampled in the W½ of Sect. 11, T.15S., R.5E., S.B.M. The trees were tallied by species and grouped into three diameter classes -- saplings, less than 12"; poles, 12" to 18"; trees, over 18". Table 1 summarizes the results of the cruise and shows the preponderance of saplings and poles.

TABLE 1

GREEN STAND COMPOSITION FROM 28 ACRES OF CRUISE STRIP

Species	Coulter Pine			Jeffrey Pine			Total
DBH Class	Sapl.	Poles	Trees	Sapl.	Poles	Trees	
No. of trees	253	123	55	700	659	297	2087
Percent of stand	12.1	5.9	2.6	33.6	31.6	14.2	100.0
Trees/acre	9.04	4.39	1.96	25.00	23.54	10.61	74.54

It proved impossible to check for the incidence of primary insects in every tree on the cruise strips. However, an intensive examination of each tree was made for the presence of pitch tubes of the red turpentine beetle, Dendroctonus valens Lec.[1/] Table 2 shows the incidence of D. v. in the stand.

TABLE 2

INCIDENCE OF DENDROCTONUS VALENS IN THE GREEN STAND FROM 28 ACRES OF CRUISE STRIP

Species	Coulter Pine			Jeffrey Pine			?	
DBH Class	Sapl.	Poles	Trees	Sapl.	Poles	Trees	Poles	Total
No. of infested trees	6	3	11	9	41	17	8	95
No. of trees in green stand	253	123	55	700	659	297		2087
No. of infested trees/acre	0.22	0.11	0.39	0.32	1.46	0.61	0.28	3.39

It is evident from Table 2 that this insect is found most frequently on poles and larger trees. No other surveys have been undertaken in the past to determine the incidence of this insect in a green stand; hence, there are no figures for comparison to determine whether or not this is normal for this insect species.

It is possible that the values obtained in this analysis may not be representative, as one of the cruise strips by random chance passed through an area which had recently undergone insect control treatment. This area was heavily attacked by D. v. within two weeks after the control work was completed and showed a much higher incidence of D. v. than

[1/] Dendroctonus valens Lec. will be abbreviated D. v. throughout this paper.

than generally was to be found in the remainder of the green stand.

Although it was impossible to sample an adequate area to show the incidence of the California flatheaded borer, Melanophila californica V. D.[2/], in the stand, reference to the results of previous investigations show a yearly variation in the frequency of this insect attack in the timber stand as a whole with a preponderance of attacks in "high-risk" trees. Bedard (1941) found, in a comparison of 69 normal trees and 271 high-risk trees at Bly, Oregon, that none of the normal trees were infested by M. c., but that 112 or 41.2 per cent of the "high-risk" trees were infested. It is logical to assume that a similar condition prevails in this area with attacks of this insect being more common on decadent rather than normal trees.

During the course of this survey a tally was made of all trees on the strip which had died in 1950. The results of this tally are shown in Table 3.

TABLE 3

1950 LOSS (CAUSE OF DEATH UNDETERMINED)
FROM 28 ACRES OF CRUISE STRIP

Species	Coulter Pine			Jeffrey Pine			Total
DBH Class	Sapl.	Poles	Trees	Sapl.	Poles	Trees	
No. of dead trees	--	2	4	6	16	3	31
Percent of green stand	--	1.63	7.27	0.86	2.42	1.01	1.49
Trees/acre	--	0.07	0.14	0.21	0.57	0.12	1.11

2/ Melanophila californica V. D. will be abbreviated M. c. throughout this paper.

From Table 3 the value of 1.11 trees killed per acre represents a very high loss rate, and is greatly in excess of the growth rate. The loss in merchantable trees alone is 0.90 trees per acre or 576.0 trees per section.

This value for merchantable tree loss compares favorably with the results obtained by Bongberg and Engen of this office in a cruise of 70.43 acres of strip samples scattered over the 5325 acres of government holdings in the area. Their cruise was made in April 1948 for a proposed selective cutting on the area to remove the dead and dying trees. The results of their cruise showed that there were 0.855 merchantable trees per acre to be removed in the cut. These trees were dead or would have been dead by the end of the season. This might be construed to represent the loss for the season, and it is very close to the value of 0.90 merchantable trees lost per acre which was obtained this season from the limited sample of 28 acres.

Decadent Tree Analyses

Upon making a general survey of the green stand, one is impressed with the large number of fading and dead trees which occur both singly and in groups. On felling 14 of these fading and dead trees an examination indicated that M. c. was present throughout the entire length of the bole, except in those trees in which the Oregon engraver beetle, Ips oregoni Eichh., occupied the top portion of the stem. The pitch tubes and galleries of D. v. also were found in the stumps of many of these trees. These three insect species apparently were the only primary infesting forest pests. The occurrence of these insects in the 14 trees, as reported by Cox, is given in Table 4.

TABLE 4

OCCURRENCE OF INSECT SPECIES IN 14 FADING AND DEAD TREES

No. of trees	Species of insects
7	D. valens and M. californica
4	Ips oregoni and M. californica
2	Dendroctonus valens
1	Melanophila californica

Examinations of the boles of many dead trees felled in the area during the spring months confirmed the results found in the 14 trees listed in Table 4. Apparently the most commonly encountered pattern of infestation in this area is a combination of D. v. and M. c. attacks. However, the loss from combination attacks of M. c. and Ips oregoni is rather extensive. Trees killed by this latter combination show a uniform fade of the needles in the infested portion of the crown, and they are found in large group kills. Snags from several years of loss as well as current kills can be found in these groups, and it seems apparent from observations that succeeding generations of Ips move from tree to tree within the group rather than moving away from each group to establish new group kills. This latter condition is generally regarded as being typical of this insect's attack in other regions.

Individual and combined attacks by M. c. and D. v. were found to be responsible for the large numbers of decadent trees on the area, whereas trees infested with Ips oregoni died rapidly and did not show this typical period of approaching death. In an attempt to determine the sequence of events and the time intervals involved in the decadence of trees infested with D. v. and M. c., one hundred and three trees were

selected for continuous observation to determine the rate of decline of such trees. These trees were described and numbered early in July 1950, and subsequent examination made in January 1951 showed that 55 of the 103 trees had died (see Table 5). Most of this loss had occurred in the trees infested with both M. c. and D. v. Of the trees attacked by D. v. alone, it is of interest to note that the greater part of the loss had occurred in those trees which had the greatest number of D. v. pitch tubes (see Table 6). This may indicate that a given number of D. v. attacks are required to effect the physiology of the host.

TABLE 5

SIX MONTHS' LOSS IN A SAMPLE OF 103 DECADENT TREES

Insects Present (July 1950)	No. of Trees Dead and Fading (Jan. 1951)	No. of Trees Alive (Jan. 1951)	No. of Trees Total
M. c. incipients	2	10	12
M. c. fast-growing	0	1	1
M. c. incipients and new or new and old D. v.	30	10	40
M. c. fast-growing and new or new and old D. v.	7	1	8
New or new and old D. v.	15	10	25
No insects	1	16	17
TOTAL	55	48	103

sufficiently to kill the tree. Further, it may indicate that D. v. is actually responsible for tree death, and that its' attacks do not merely indicate approaching death.

TABLE 6

ANALYSIS OF NUMBER OF PITCH TUBES ON 25 TREES ATTACKED BY DENDROCTONUS VALENS

No. of Pitch Tubes (July 1950)	No. of Trees Dead and Fading (Jan. 1951)	No. of Trees Alive (Jan. 1951)
1	1	1
2	1	2
3	1	
4		2
8	1	1
10		1
12		2
14	1	
15	2	
17	1	
19	2	
23	1	1
30	1	
?	3	

It was desired to determine whether or not M. c. or D. v. made a preferential selection of trees in any particular Keen class. Hence, an analysis was made of the frequency of occurrence of both insects in each of the 16 Keen tree classes which were represented in a sample of 104 decadent trees. There were not enough trees in each age class to give an adequate sample; however, a summation of the data by crown vigor classes (see Table 7) indicated that with the exception of class "a" crowns, which are represented by a small sample, the insects occur no more frequently in trees with vigorous crowns, class "b", than in trees with shorter sparser crowns, classes "c" and "d".

TABLE 7

FREQUENCY OF *M. CALIFORNICA* AND *D. VALENS* ATTACKS IN 104 OBSERVATION TREES WITH RESPECT TO CROWN VIGOR CLASSES

Insect	*M. californica* (larvae)						*D. valens* (pitch tubes)						
Type of Attack	Incip.		Fast Grow.		Total		New		Old		New & Old		Total		Total Trees Obs.
Crown Class															
a	6	67%	-	-	6	67%	-	-			3	33%	3	33%	9
b	19	50%	3	8%	22	58%	14	37%			14	37%	28	74%	38
c	19	46%	3	7%	22	54%	20	49%	2	5%	10	24%	32	78%	41
d	7	44%	3	19%	10	62%	7	44%			5	31%	12	75%	16
TOTAL	51	49%	9	9%	60	58%	41	39%	2	2%	32	31%	75	72%	104

Growth Studies

In the voluminous correspondence of the past few years regarding this area, many references have been made to the "drought" conditions which have been prevailing. The following study was undertaken to determine the factual nature of this condition. To accomplish this, it was necessary to determine the normal and seasonal growth and precipitation patterns during the last 50 years.

Growth Pattern

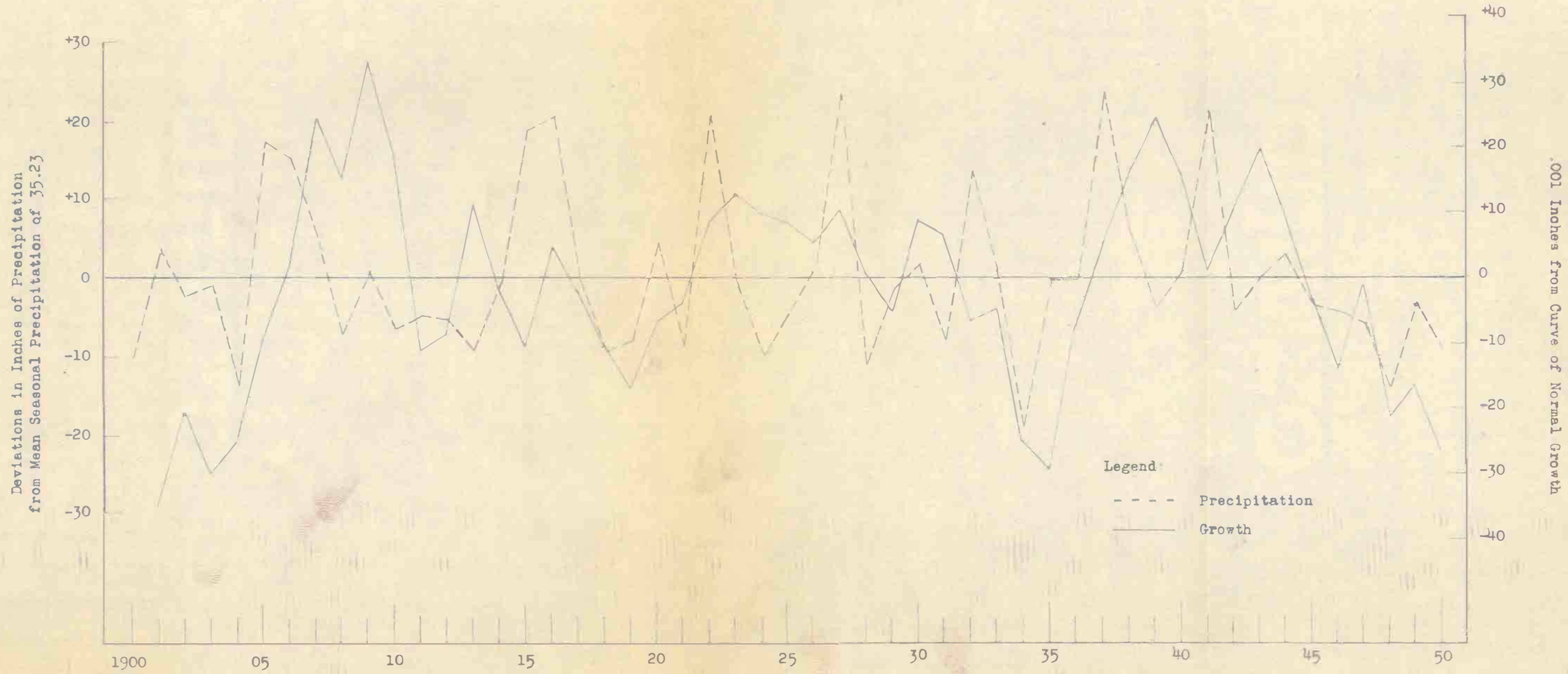
By the use of a Swedish increment borer, radial increment cores were taken in the Laguna Campground area from 16 "index trees" (Keen classes 2a and 3a) as described by Keen (1937). The cores were labelled and allowed to dry completely in the air. Prior to measurement they were boiled in water until they sank, assuring that there was a uniform water saturation in all cores. The rings were measured consecutively

and the values of annual increment obtained were plotted on graphs. A Comparison of key years of growth was made to eliminate the possibility of error resulting from some trees having missing or incomplete growth rings. The average annual increment was obtained for the 16 trees and the annual growth curve was plotted from these values. The normal growth curve was secured by drawing a smooth curve through the points determined by averaging the growth for 3 twenty-five year periods: 1901-1925, 1914-1938, 1926-1950. The annual deviations from the normal curve were measured directly from the original graph and are listed in Table 8 and plotted in Figure 1. In that the loss on the area apparently did not predominate in any of the four crown vigor classes, no attempt was made to determine the variations in radial growth associated with variations in crown vigor classes.

Precipitation Pattern

The monthly and annual precipitation data from the best available local weather stations was obtained from U. S. Weather Bureau sources. This data was used to compute the seasonal July to June rainfall. Precipitation records were taken in the Laguna Mountain area for only a brief period during the war years at the Civil Aeronautics Authority observation station. These records are of little value due to inaccuracies in the measuring techniques, and they obviously do not represent the true precipitation conditions in the area. Consequently, it was necessary to use data from the long-record stations at Cuyamaca and Julian. An average of the records of these two stations has been used to determine the 50-year seasonal, precipitation pattern and the average of the 50-year record is used as the normal precipitation for this period.

Figure 1.--Annual Deviations of Growth and Precipitation from Normal -- 1900-1950



The seasonal deviations from the normal have been calculated and are listed in Table 8 and plotted in Figure 1.

In all of these considerations one must keep in mind that the precipitation data used in this analysis is an average of the data from two stations neither of which have similar timber types nor a timber type like that of the Laguna area. While the Mt. Laguna stand is practically pure Jeffrey pine with some mixtures of Coulter pine on the margins, the Cuyumaca area is characterized by typical westside Sierra mixed conifer stands. The Julian stand on the other hand is nearly pure Coulter pine. The nature of the timber type in addition to the differences in elevation and incidence of summer and winter storms indicates that there is a great deal of variation in the actual precipitation conditions which prevail in the Laguna area as compared with the precipitation in the areas from which the data used in this analysis was taken.

Although no permanent record has been kept of the water level in Big Laguna, Little Laguna, and Cuyumaca reservoirs, it is apparent from talking to the residents near these areas that the lakes normally have some water in them. However, it is of interest to note that all of these reservoirs have been dry for the past few summers. This may be a further indication of the drought conditions which have prevailed in the area during the last five years.

Relation of Growth Pattern to Precipitation Pattern

Comparisons of the annual deviations from normal growth and seasonal deviations from normal precipitation have been made by means of a correlation analysis. The growth of the 1950 season had not been completed at

TABLE 8

GROWTH AND PRECIPITATION DATA -- 1900-1950

Year	Seasonal Precip. [1]	Ave. Seas. Precip.	Annual Variation from Ave. Seas. Precip.	Annual Variation from Normal Growth Curve [2]
1950	26.30	35.23	- 8.93"	-26.2(.001 in.)
1949	31.58	"	- 3.65	-16.2
1948	20.71	"	-14.52	-21.7
1947	29.24	"	- 5.99	- 1.0
1946	30.66	"	- 4.57	-14.5
1945	31.30	"	- 3.93	- 3.4
1944	36.86	"	+ 1.63	+ 9.7
1943	34.96	"	- 0.27	+19.0
1942	30.41	"	- 4.82	+10.0
1941	56.06	"	+20.83	+ 0.7
1940	35.95	"	+ 0.72	+15.0
1939	31.44	"	- 3.79	+24.6
1938	41.02	"	+ 5.79	+16.2
1937	59.12	"	+23.89	+ 5.6
1936	34.37	"	- 0.86	- 7.7
1935	34.38	"	- 0.85	-29.6
1934	15.87	"	-19.36	-25.4
1933	35.98	"	+ 0.75	- 4.2
1932	48.68	"	+13.45	- 6.2
1931	26.80	"	- 8.43	+ 6.8
1930	36.70	"	+ 1.47	+ 8.8
1929	33.42	"	- 1.81	- 5.1
1928	23.58	"	-11.65	+ 0.7
1927	58.43	"	+23.20	+10.5
1926	36.12	"	+ 0.89	+ 5.7
1925	30.60	"	- 4.63	+ 8.2
1924	25.15	"	-10.08	+ 9.7
1923	34.19	"	- 1.04	+12.8
1922	55.40	"	+20.17	+ 8.6
1921	26.31	"	- 8.92	- 3.9
1920	39.82	"	+ 4.59	- 6.9
1919	26.95	"	- 8.28	-17.2
1918	25.78	"	- 9.45	-10.4
1917	35.22	"	- 0.01	- 1.9
1916	55.40	"	+20.17	+ 4.4
1915	54.08	"	+18.85	-10.3
1914	35.16	"	- 0.07	- 1.5
1913	25.92	"	- 9.31	+11.4
1912	29.30	"	- 5.93	- 8.3
1911	30.25	"	- 4.98	-11.2
1910	28.64	"	- 6.59	+18.5

TABLE 8 (CONTINUED)

YEAR	Seasonal Precip. [1]	Ave. Seas. Precip.	Annual Variation from Ave. Seas. Precip.	Annual Variation from Normal Growth Curve [2]
1909	36.32	35.23	+ 1.09"	+33.3(.001 in.)
1908	27.40	"	- 7.83	+15.2
1907	40.55	"	+ 5.32	+24.7
1906	50.78	"	+15.55	+ 1.2
1905	52.28	"	+17.05	- 9.3
1904	21.06	"	-14.17	-24.8
1903	33.96	"	- 1.27	-29.3
1902	32.51	"	- 2.72	-20.8
1901	38.66	"	+ 3.43	-35.1
1900	25.01	"	-10.22	--

[1] Values in this column represent the seasonal average of precipitation at Julian and Cuyumaca. However, the Julian record was not complete, 1900-1908; hence, values for this period were obtained by determining the average annual percent deviation of the Julian record from the Cuyumaca record and by applying this average percent deviation to the Cuyumaca record for the 1900-1908 period.

[2] Growth data taken from trees growing at Laguna Mountain.

the time that the cores were taken; hence, the comparison of growth and precipitation for that year has been excluded from these analyses.

A correlation coefficient of + 0.174 ± 0.138[3/] was secured in an analysis of the corresponding seasonal precipitation departures and the annual deviations from the curve of normal growth. However, this value is not significant, in that a value this great or greater could have been obtained by chance alone. It is surprising that a value this low was obtained. Previous analyses of pine growth and its relation to precipitation by Keen (1937) in eastern Oregon, + 0.50 ± 0.109; Douglass (1933) in the San Bernardino Mountains, California, + 0.45; and Hawley (1941) in the Mississippi drainage, + 0.52, have resulted in similar, more highly significant values. The low value obtained in this study may reflect the small number of trees which were sampled, or it may indicate that tree growth is not as dependent upon the precipitation in this area as it is in other areas. It is to be noted that even in the driest years, the seasonal precipitation has not fallen below the critical level for tree growth.

Hawley, Douglass (1928), and Keen (1937) have used various methods of smoothing growth curves to eliminate the excessively high and low spots in the curves, which result from such factors as localization of storms, excessively steep land contours, etc. Smoothing may also take into account the possibility of some holdover of the effects of dry or

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3/ One must not infer from this figure that there is a 17.4 percent correlation between precipitation and growth as Douglass (1936), and Antevs (1938) have done in similar cases. This value merely shows whether or not the two series of factors are correlated.

wet years into one or more of the following seasons. Keen (1937) found that a higher degree of correlation was obtained between annual growth and the cumulative departures of precipitation of the current and preceding years than was obtained from the departure of current seasonal precipitation alone.

On this latter basis an attempt was made to determine whether seasonal growth was better correlated with the departure of the current year's precipitation or with the cumulative departures of precipitation for two or more years. The correlation coefficient for the cumulative departures of precipitation for two years was found to be + 0.344 ± 0.126, and for the cumulative departure of precipitation for three years was found to be + 0.395 ± 0.087. These values are significant at the 5 per-cent level of significance, and it is apparent from these values that cumulative departures of precipitation are more significant than annual departures when correlated with tree growth. This is in direct agreement with the conditions found by the other workers mentioned, and it indicates that trees in this area are more dependent on the precipitation of several seasons than on the precipitation of the current season. This may be of some consequence when one considers that since 1945 this area has experienced a greater cumulative deficiency of rainfall than it has at any other time in the last 50 or more years.

Drought Pattern

It is obvious from Figure 1 that drought or subnormal precipitation conditions have prevailed in this area since 1945. However, the interpretation of future conditions is very difficult. Many workers in the field of tree ring analysis have maintained that precipitation and the resulting

tree growth follow a measurable, cyclic pattern by which it is possible to predict the precipitation of the future. This then, if correct, would make it possible to foresee periods of drought or abundant precipitation. Keen (1937) approached the problem of controlling bark beetles with this in mind, and after exhaustive investigations came to the conclusion that "there is nothing to indicate that the apparent cycles of growth are anything more than chance variations."

Therefore, one must consider both of these schools of thoughtin interpreting the curves of Figure 1. If Douglass and his co-workers are correct in presuming that precipitation does follow a cyclic pattern then possibly we might be able to predict a tendency for the large deviations from the normal precipitation in recent years to return to the normal condition within a few years. However, the growth in recent years has yet to reach the lows found at the turn of the century or in 1935, which may mean that more dry years can be expected.

From these studies, however, it seems apparent that neither growth nor rainfall show any cyclic pattern during the 50-year period which was studied, and it is probable that nothing more than chance variation in rainfall may be expected in the seasons which are to follow.

Relation of Cause of Loss to Precipitation Pattern

By virtue of the incomplete and variable nature of the loss record for this area, it seems impossible to correlate the various periods of high or low precipitation with the incidence of any of the biological agents which have played an important part in the decadence or death of the trees in the past.

It should be noted, however, that the intensive bark-beetle control work by the CCC from 1934 to 1940 may have been the result of the below normal precipitation from 1934 through 1936. On the other hand, the losses in the latter part of the '30s probably resulted predominantly from root rot, Fomes annosus (Fr.) Cke. The first report of loss from this agent in the Mt. Laguna area was by DeLeon (1941) in the season of 1940. His study was conducted to determine why the intensive insect control in this area was not successful in reducing mortality. The four years of above-normal rainfall in the 1937-1941 period may have been an important factor in the great increase in loss due to root rot. In the last ten years, losses due to this fungus have decreased steadily until they currently have become almost non-existent.

It is not possible at this time to postulate whether or not this decrease in the incidence of F. annosus as a primary factor in loss can be attributed to the general sub-normal precipitation which has prevailed in the area since 1942. Dr. W. W. Wagener, Senior Pathologist, Bureau of Plant Industry, Soils, and Agricultural Engineering, has followed the course of this infection very closely from the time of the first observations to the present. He visited the area during the 1950 field season and his observations are quoted from his recent correspondence to this office. "It appears that this fungus which in the early '40s was causing the death of hundreds of trees around Mt. Laguna, has currently become almost non-existent as a source of loss . . . . . The most likely explanation for the pronounced drop in Fomes annosus activity is that conditions for the transfer of the disease from affected to sound roots became unfavorable . . . . . It seems likely that the drop in infection of new root systems probably occurred about the start of the series of dry

years that has plagued the Southland." He stresses that this latter statement is purely hypothetical, and until such time as adequate experimentation can be conducted on this problem no definite statements can be made on the interrelationship of drought, host vigor and primary biological agents.

Girdling Studies

After the primary entomological factors in tree decadence and death had been investigated, limited girdling experiments were undertaken for two purposes: (1) to show the effect of varying tree conditions on the insects present and (2) to simulate the effect of various insects on the host. Wherever, possible, the experiments were duplicated and control trees were selected as close to the treated trees as was possible. The treating was carried out during the first week of July, and it was expected that at least some of the trees would show a visible effect of the treatment by the end of the summer. However, by the first week in September, only one of the trees included in this study showed any significant change in its condition, and this tree had received far more drastic treatment than any of the others. In that most of the trees had shown no obvious effects of the treating, it was decided to leave them standing for observation during the following seasons. Therefore, no conclusions can be drawn from this phase of the investigations; however, the data on each tree is included in Table 9 to indicate the nature and intent of the treatments which were conducted. The techniques employed in girdling are illustrated in Photos 1a, 1b, 1c.

In tree G-9 the attempt to initiate the fast-growing condition in the incipient larvae of M. c. by girdling methods was overshadowed by

Table 9.--Description and Treatment of Girdled Trees

Tree No.	Keen Class	Risk	Insects in Bole: Top	Mid	Bottom	Needle, Length and Color: Top Crown	Mid-crown	Lower Crown	Descrip. of girdle	Girdled to show
G1	2a	2	Mc.	Mc.	No Dv.	Green, medium to short		Fading, medium	Phloem girdled at 20 ft. from the ground.	Effect of phloem girdle on development of Mc. and effect of girdle on susceptibility of tree to Dv.
G2	2a	2	Mc.	Mc.	New & old Dv.	Green, medium to short		Fading, medium	Not girdled	Control tree for comparison with G1. Trees are identical and side by side.
G3	2b	2	Mc?	Mc?	No Mc. or Dv.	No fading at all, short needles throughout			Phloem and $\frac{1}{8}$" of sapwood removed at $\frac{1}{2}$' from the ground line.	A simulated Dv. girdle. Tree should not show effects for 2 or more yrs.
G4	2b	2	Mc?	Mc?	Mc. & Dv.	Green, medium to short	Green, medium	Green, medium but fading and red in places	Not girdled	Control tree for comparison with G3. Trees are identical and side by side.
G5	2b	4	Mc.	Mc.	No Mc. only one Dv.	Needles equally faded and short throughout.			Phloem girdled on W $\frac{1}{2}$ of tree at 19' from the ground. Vertical extensions from end of girdle.	Effect of girdle on development of Mc. In contrast to development on the girdled $\frac{1}{2}$ of bole. Vertical extensions to reduce lateral translocation in the phloem.
G6	2b	2	Mc?	Mc?	Mc. New Dv. Girdles butt	Yellowish short	Fading or red, short. Many dead or clubbed branches.		2/3 of butt girdled, 1/3 is phloem only and the other 1/3 is phloem and sapwood. Vertical extensions to separate each 1/3.	Effect of different girdles on Dv.
G7	2a	3	Mc?	Mc?	Mc. New & old Dv.	Yellowish short	Yellow & red, short. Many dead branches.	Vigorous needles, many broomed branches.	Not girdled.	Control tree for comparison with G6. Check normal development of a Dv infested tree.
G8	2b	3	Mc?	Mc?	No Mc. No Dv.	Needles short and faded throughout. Lower branches poorest with more fading.			Phloem and $\frac{1}{8}$" of sapwood removed at $\frac{1}{2}$' from the ground line	Duplication of G3 on a different area. Attempt to simulate Dv attack at base, and to induce fast-growing condition in incipients above.
G9	1c	3	Mc	Mc	Mc. New & old Dv.	Green, medium but thin complement	As in top, but with red needles on two east branches.	Several branches with long red needles, no green needles	1 to 2" axe cut was made into the sapwood on W $\frac{1}{2}$ of the stem at 5' from the ground line. Vertical axe cuts were made to prevent lateral translocation of water into the area above the girdle.	Immediate effect of deep cut to incipients above and below the girdle. Attempt to see if letting the tissue dry out would cause incipients to change to fast-growing.

Photo No. 1.[1]--Tree No. G-8, girdled July 6, 1950 to simulate a *Dendroctonus valens* attack at the base of the tree in an endeavor to induce the fast-growing larval stage of *Melanophila californica* in the bole of the tree.

a. Using a turpentining tool to girdle the phloem and outer 1/2-inch of sapwood. Note the sapwood moisture sample directly above the tool.

b. Painting the girdled area and moisture sample with tree paint to prevent undue desiccation.

c. Screening and sealing the girdled area with plastic screen and dirt to prevent subsequent insect attack to the injured area.

[1] Photos taken by David Cox.

the complete girdling of the trunk at the ground line by D. v. In this case, the fast-growing stage developed in the entire stem without restriction to the artificially girdled area as was anticipated.

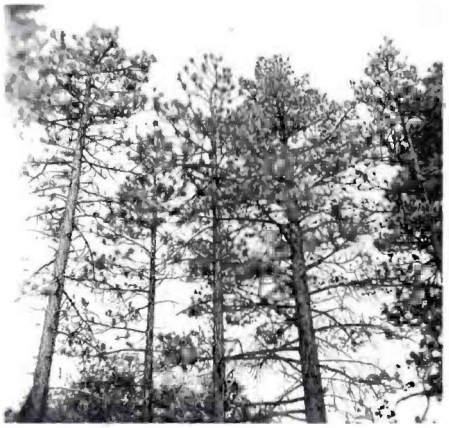
The important role of D. v. in the mortality of trees on this area was not appreciated at the time that these experiments were conducted; hence, they were not directed toward shedding any light on the problems presented by this insect.

Crown Studies

Although no actual crown analyses were made, it was apparent from observations that trees attacked by combined M. c. and D. v. showed crown characters which could be readily identified in the field. In general, the trees infested by these insects appeared to have pronounced fading of the needles in the lower crown and a thin, short, feathery, needle complement which gave a tufted or cup-shaped appearance to the branch tips. This latter condition was particularly prevalent in the upper-most branches, but sometimes it extended throughout the entire crown (see Photo 3).

Upon investigation it was noted that these cup-shaped tufts at the branch tips resulted from very reduced growth of the current year's needles. In some extreme cases the new needles had not even emerged from the fascicle sheaths. This condition was associated with what appeared to be a premature loss of many of the older needles which normally persist five or six years. These two factors accounted for the open, feathery appearance of the crown and the tufted appearance of the needles at the branch tips.

Photo No. 3.[1]—Crowns of decadent (D) trees showing feathery tufted needle complements in contrast to trees with full needle complements. Most of the decadent trees were infested with Dendroctonus valens and Melanophila californica.



[1] Photos taken by David Cox.

It was anticipated that the girdling experiments discussed in the preceding section might produce crown conditions similar to those observed in infested trees, and thus give some clue as to the factors which might have been causing these crown conditions. However, sufficient time has not passed as yet to determine if these experiments will successfully induce these crown characteristics. The change of the condition of the crown probably is a very slow process taking one to three or more years. Reexamination of the permanent plots established this season at periodic intervals may give some idea of the length of time involved in this process.

From this season's work it is impossible to state whether the insect attacks caused the crown condition or whether they merely were associated with the crown decadence caused by some other agent. It is only possible to speculate on the cause of this characteristic crown condition. It seems doubtful that these crown symptoms are the result of edaphic or moisture variations. One usually thinks of particular edaphic or moisture conditions as being common to rather large areas with most of the trees on a given area responding in a similar manner to specific conditions. However, on any one site, slope, or exposure in this area, it is possible to find paired trees of identical crown class standing side by side with one having a perfectly normal crown and the other showing the characteristics of decadence given above. This would lead one to the conclusion that variations in edaphic or soil moisture conditions have little effect upon the development of these poor crown characteristics.

One possible explanation for this variation is that there may be great differences in the root systems of trees exhibiting different crown

conditions. Bedard (1944), working with small ponderosa pine saplings, found that pruning of lateral roots and tap roots gave a significant reduction in needle length and needle weight. Craighead (1941) has also recorded that severe drought conditions in a small white pine plantation resulted in the reduction of needle growth to only ½ - 1 inch in length in contrast to the normal annual growth of 3-5 inches. Similarly, Schantz-Hansen and Joranson (1939) found a large reduction in needle length, radius of cross-section, and average needle area caused by excessive drought in 1936 at the Cloquet Forest Experiment Station. This held for northern white pine, Norway pine, and jack pine. In addition to the shortening of the needles during the drought year they noticed "the presence of an abnormally large number of brown needles and the occurrence of an unusually heavy needle fall . . . . ."

These references and others indicate that there may be a possibility that the short, current, needle length and early needle drop may be the result of both the drought conditions prevalent in the area and variations in the root systems of individual trees. Any further work on this problem certainly should consider these factors, and it is possible that complete root excavations and various fertilization and starvation treatments of root systems may give further indications of the factors which contribute to the decadent crown characteristics.

Anatomy Studies

In planning this investigation prior to the field work, a study of the variations in the wood anatomy of the host associated with the attacks of the various primary insects was proposed. This was to have included an attempt to correlate the incidence of insect attack with such

factors as: quantitative annual production of resin canals, annual periodicity of resin canal production, and periodicity of cambial growth. These studies, however, had to be abandoned when investigation showed that D. v. and M. c. could be found in all stages of development in trees of all age and crown classes, on all sites, at nearly any period during the growing season of the host. Thus their attacks apparently were not correlated with the factors given above.

Moisture Studies

It was possible during the field season to carry out several studies of the variations in the moisture relations within the host. Perhaps, the most extensive of these was the sampling of sapwood and phloem from 104 observation trees. The insect conditions present in each of these trees were known, and an attempt was made to correlate sapwood and phloem moisture with several different insect-host relationships.

Method of Sampling

The samples for this study were obtained by the use of a 1½-inch arch punch, hammer, and extractor. The arch punch was driven into the tree until a core of bark, phloem and approximately one-half inch of sapwood had been secured (see Photo 2). The punch was removed from the tree, and the sample extracted. The sapwood and phloem then were separated at the cambium with a sharp knife. The functional phloem was removed from the bark and wrapped in aluminum foil to prevent dessication before weighing. The cambial one-quarter inch of sapwood was cut from the sapwood plug, and it, too, was wrapped in aluminum foil. When as many samples had been collected as could be dried at one time, the

samples were taken to the Camp Ole laboratory.

The wet weight of sample and foil was taken on a torsion balance. Then the samples were unwrapped and placed loosely in the foil on the racks of an electric laboratory oven for drying at 170-180°F. The oven was equipped with a 12-inch fan which blew across an open vent at the top of the oven. In this way a forced draught effect was secured, and it was possible to reduce the temperature in the oven as much as 60°F. without reducing the heat output of the oven coils. Thus sufficient hot air was moved through the oven past the samples to give a rapid drying effect at comparatively low drying temperatures. By the use of this system it was possible to remove enough of the water from the samples in three hours, so that in an additional twelve hours of drying, it was only possible to remove 0.1 - 0.3 grams of water. Thus the values obtained in 3 hours of drying never were more than 1 percent in error from the values obtained by much longer drying. It also was probable that prolonged drying would have resulted in a physiological breakdown of the samples being dried with a resulting water loss in excess of the actual amount of water in the cells.

Following drying, the dry weight of the sample plus foil and the dry weight of the foil alone were determined. The necessary calculations then gave the moisture in the sample as the percent of dry weight. This procedure with the exception of the drying technique follows the method developed and used by Hall (1949) and Struble (1947, 1949). Criticisms of the method and variability of moisture within the host are discussed in their papers.

Moisture Variations by Keen Tree Classes

Although D. v. and M. c. apparently attack without indicating a host preference in this area, it was postulated that trees representing the various crown and age classes of the Keen tree classification might show significant variations in the moisture conditions of their sapwood or phloem. An analysis of the average moisture of sapwood and phloem for each of the Keen tree classes which were included in the sample is given in Table 10.

TABLE 10

AVERAGE SAPWOOD AND PHLOEM MOISTURE FOR VARIOUS KEEN TREE CLASSES

Keen Class	1a	1b	1c	1d	2b	2c	2d	3a	3b	4c	Total
No. of Trees	7	31	36	15	6	4	1	2	1	1	104
Ave. Sap. Mois. % of Dry Wt.	108.6	102.4	105.8	97.3	103.3	85.0	120.0	92.5	165.0	95.0	103.2
Ave. Phl. Mois. % of Dry Wt.	174.3	154.4	160.3	164.7	160.8	158.8	160.0	170.0	165.0	205.0	160.7

Although the size of the sample in each class is limited in Table 10, the samples in classes 1a, 1b, 1c, 1d, seem to be adequate to provide a basis for comparisons of the averages obtained. It is apparent that the average moisture values for each of these Keen classes show no significant variations or trends. Hall's work on ponderosa pine in northern California in which he sampled four trees in each of the 16 Keen tree classes also "failed to show any consistent association between phloem moisture and tree class . . . . .". However, after a similar study Beal (1930) concluded that "the moisture of the phloem decreases with the size of the crown, there being little difference in the age classes."

A further analysis of the data of Table 10 failed to show that there was a significant variation in sapwood or phloem moisture associated with the age class (Table 11) or the crown vigor class (Table 12) of the trees used in this sample. This concurred with the results of Hall and Beal with respect to there being little difference in the phloem moisture of trees of different age classes. However, it does not concur with Beal's results with respect to crown vigor classes in which he found that phloem moisture decreases with the size of the crown.

TABLE 11

AVERAGE SAPWOOD AND PHLOEM MOISTURE BY KEEN AGE CLASSES

Keen Age Class	1	2	3	4	Total
No. of Trees	89	11	3	1	104
Ave. Sap. Moisture	103.4 ± 11.2	98.2 ± 32.0	116.7 ± 121.7	95.0 ± ∞	103.2 ± 10.3
Ave. Phl. Moisture	160.1 ± 17.3	160.0 ± 51.1	168.3 ± 119.1	205.0 ± ∞	160.7 ± 16.0

It is apparent from the magnitude of the standard errors in Tables 11 and 12 that an analysis of hundreds of trees in each class would be necessary to obtain mean values which would show significance. In addition, it must be kept in mind that most of these 104 trees were infested with various insects which condition might have altered the moisture values from those which one might find in uninfested trees of similar Keen classes. However, investigations to be discussed in the next section of this report indicate that insect attacks have little or no effect on the host moisture conditions.

TABLE 12

AVERAGE SAPWOOD AND PHLOEM MOISTURE BY KEEN CROWN VIGOR CLASSES

Keen Crown Vigor Class	a	b	c	d	Total
No. of Trees	9	38	41	16	104
Ave. Sap. Moisture	105.0 ± 37.4	104.2 ± 17.5	103.5 ± 16.6	98.8 ± 25.8	103.2 ± 10.3
Ave. Phl. Moisture	173.3 ± 61.5	155.6 ± 26.1	161.3 ± 25.7	164.4 ± 42.8	160.7 ± 16.0

Moisture Variations as Affected by Insect Attack

The 104 trees on which the moisture variations were to be analyzed had been inspected for the presence of D. v. and M. c. When the sapwood and phloem moisture determinations had been completed on each tree, a frequency distribution was made of the number of trees infested with different insect combinations in each sapwood and phloem moisture class (see Figure 2). The infestations were considered in two ways: (1) Cases in which only a single insect was present, and (2) cases in which an insect was found working both individually and in combination with another insect. Both of these will be discussed in turn.

(1) It was anticipated that there might be a significant variation in the moisture relations of trees which have different developmental stages of one insect present in their tissues. Hence, an analysis was made of fifty-six trees, each of which had a developmental stage of M. c. or D. v. (see Table 13). A comparison of the averages of sapwood and phloem moisture of the various columns in Table 13 indicates that the presence of a single entomological factor, regardless of the species or stage of development, does not result in a significant deviation

of the means of sapwood or phloem moisture from the means found in uninfested trees or trees infested with different entomological factors. This is quite obvious when one considers the magnitude of the standard errors of each mean.

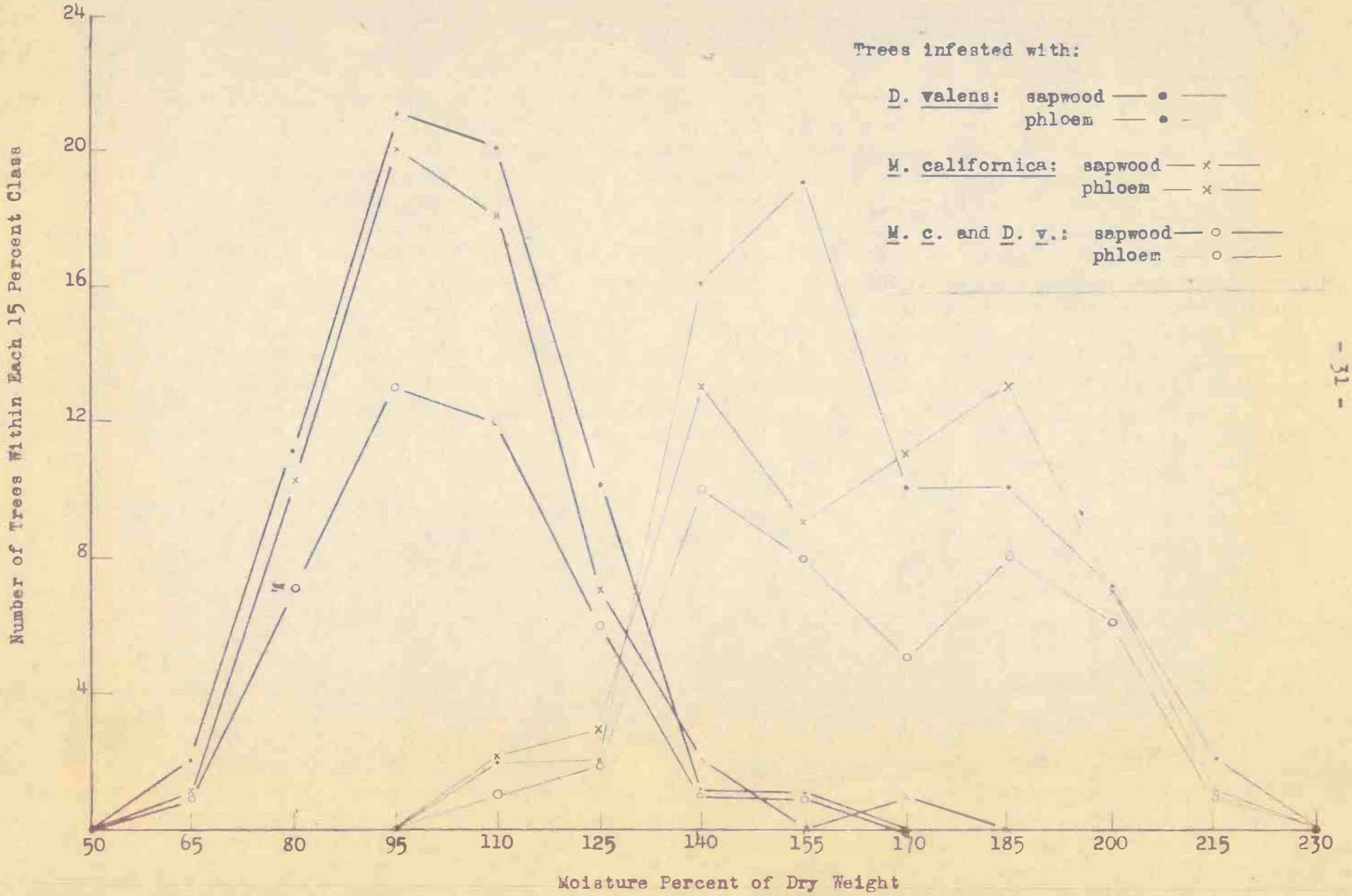
TABLE 13

AVERAGE SAPWOOD AND PHLOEM MOISTURE OF TREES INFESTED WITH A DEVELOPMENTAL STAGE OF MELANOPHILA CALIFORNICA OR DENDROCTONUS VALENS

Column No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Insect Species	M. californica (larvae)			D. valens (pitch tubes)				
Stage of Development	Incipient	Fast-Growing	Total	New	Old	New & Old	Total	No Insects
No. of trees	11	1	12	22	0	5	27	17
Ave. Sap. Moisture	102.7 ± 32.8	90.0 ± ∞	101.6 ± 30.9	106.3 ± 23.5	-	90.0 ± 45.1	103.3 ± 20.5	104.1 ± 26.5
Ave. Phl. Moisture	167.2 ± 53.4	145.0 ± ∞	166.2 ± 50.4	156.5 ± 34.4	-	153.0 ± 77.5	155.9 ± 30.8	157.3 ± 39.5

(2) It also was anticipated that the sapwood or phloem moisture associated in a single tree with one or more different stages of insect development would show a significant deviation from the average moisture values for the uninfested trees. In this analysis (Table 14) each stage of development of both insect species was considered regardless of whether it occurred singly or in combination with other factors. A comparison of the mean values of sapwood and phloem moisture and the respective standard errors from Table 14 indicates that none of the variety of individual and combination attacks of the various stages of these two insect species are associated with significant variations in the sapwood or phloem moisture

Figure 2.--Frequency Distribution of Sapwood and Phloem Moisture Values of Infested Trees



of the host. Figure 2 shows the frequency distribution of the moisture values for both sapwood and phloem in trees attacked by M. c., D. v., and combinations of M. c. and D. v. (columns 3, 7, and 8, respectively of Table 14). It is of interest to note in all cases the regularity of the sapwood moisture curves in contrast to the irregularities and wide ranges of the phloem moisture curves.

TABLE 14

AVERAGE SAPWOOD AND PHLOEM MOISTURE OF TREES INFESTED WITH ONE OR MORE DEVELOPMENTAL STAGES OF MELANOPHILA CALIFORNICA, DENDROCTONUS VALENS, OR BOTH

Column No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Insect Species	M. californica (larvae)			D. valens (pitch tubes)					
Stage of Development	Incipient	Fast-Growing	Total	New	Old	New & Old	Total	M.c.& D.v. 1/	No Insects
No. of trees	51	9	60	40	2	32	74	48	17
Ave. Sap. Moist.	100.0 ± 14.6	100.5 ± 35.9	100.1 ± 13.4	103.4 ± 16.8	97.5 ±98.3	101.5 ± 18.5	102.4 ± 12.2	101.8 ± 15.1	104.1 ± 26.5
Ave. Phl. Moist.	162.5 ± 23.3	163.3 ± 59.9	162.7 ± 21.5	158.5 ± 25.6	162.5 ±165.0	160.6 ± 19.4	159.5 ± 18.9	162.0 ± 24.0	157.3 ± 39.5

1/ Only those trees which had both a stage of M. c. development and a stage of D. v. attack were included in this analysis.

Further consideration will be given to the influence of infestations on the variations in host moisture in the section dealing with insect-host relations.

Moisture Storage Capacity of the Tree

Apparently the death of a tree is dependent upon the breaking of the columns of water which move through the tree from root to crown. This is followed by the subsequent drying of the stem after the water columns have been disrupted. It also has been made apparent by many workers; i.e., Caird (1931), Crafts et al. (1949), Priestly (1935), MacDougal et al. (1929), Baker and James (1933), that the outer four to six sapwood rings function primarily in the translocation of water and solutes upward in the stem and that the rings consecutively inward become progressively less functional in this role. However, the inner rings seem to function as storage tissues for the water resources of the trees. The water in these inner rings is readily available for lateral movement to the outer conducting rings and vertical translocation to the crown in periods in which the hydrostatic system of the tree is under great stress. When the storage region is modified and becomes heartwood, however, it no longer functions in this manner.

On the basis of this understanding, an attempt was made to determine the volumetric capacity of the sapwood of various normal and decadent trees to determine whether one tree had a better chance of survival than another by virtue of its capacity to accumulate greater water reserves for use during critical periods of drought or insect attack. This study proved to be of little value because it was impossible to define the heartwood from the sapwood in the majority of the young trees which comprised this stand. It is of interest to note, however, that Bedard (1941), while studying a similar problem, found a significant decrease in the radial width of sapwood in high-risk trees as compared with normal trees.

Perhaps this indicates that high-risk trees have a reduced storage capacity in contrast to low-risk trees.

Several trees were encountered in the area during the field season, which apparently had living crowns, but an examination of the bases of these trees revealed that the stumps were completely girdled by D. v. and that both sapwood and phloem in this region were non-functional. This led to the supposition that the heartwood or inner sapwood layers of the tree might function in the translocation of water from roots to crown if the sapwood could not carry out this function. One of these trees was analyzed for sapwood and heartwood moisture variations in the various parts of the bole of the tree (Figure 3). Both the sapwood and heartwood of this tree showed a general increase in moisture from the stump to the mid-crown. The samples from the stump showed that the moisture in that region in both tissues was only sufficient to assure fiber saturation. Upon considering these points, it was obvious that the heartwood was not functioning in the translocation of water after the sapwood had ceased conducting.

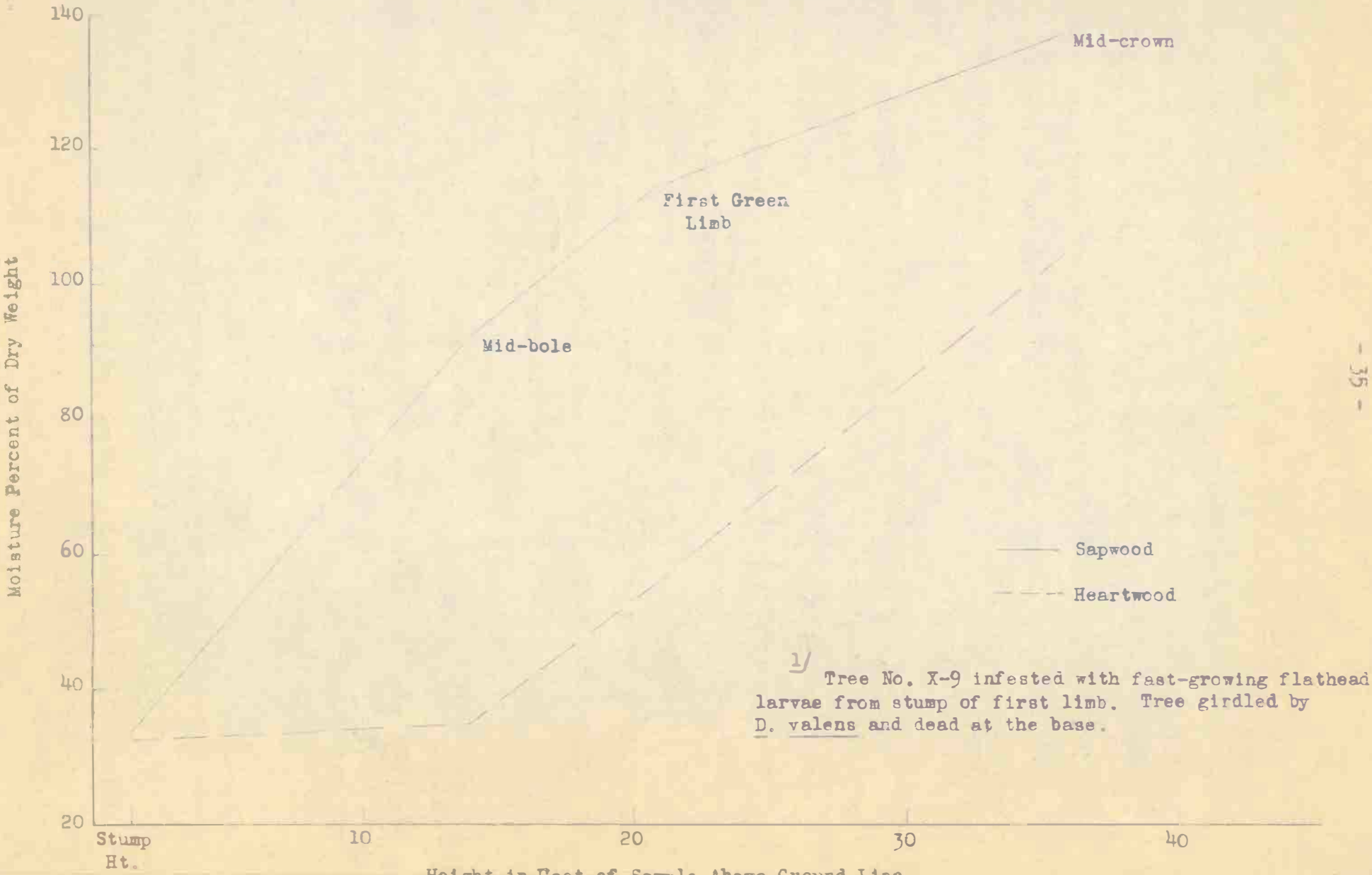
Insect-Host Studies

The following studies were conducted to show, if possible, the responses of the host to individual and combined attacks of M. c. and D. v.

Melanophila californica

After examining many infested dead and dying trees in the area it was postulated that apparently the fast-growing stage of M. c. did not develop until the tree was physiologically dead from the action of some other biological agent. However, it also was possible that the incipient

Figure 3.—Sapwood and Heartwood Moisture at Various Positions in the Bole of an Apparently Living Tree[1/]



1/ Tree No. X-9 infested with fast-growing flathead larvae from stump of first limb. Tree girdled by D. valens and dead at the base.

stage of M. c. was causing a reduction in vigor leading to the ultimate death of the host. This section of the study was conducted to determine the factual nature of both of these conditions; however, very little evidence has been found to support or reject the postulation.

Previous studies.--Miller and Keen (1945) have surveyed the reports of investigations on this problem; West (1937) studied the anatomy of the sapwood to determine the effect of the incipient larvae upon tree growth; Salmon and Johnson (1940) studied the movement of water through and around the scars produced by the incipients to determine the effect of the scar on sapwood conduction; Salmon (1940) studied the effect of incipient scars upon tree growth rate and the relation of these scars to risk in ponderosa pine to determine the various types and numbers of trees which were infested.

A general conclusion may be drawn from these studies. Apparently the presence of incipient larval mines is associated with, if not the cause of high risk and recent suppression of the growth rate of infested trees. This may be brought about by the definite blocking effect of the incipient scars upon the conduction of water and solutions through the sapwood of the host.

These well-conducted studies reflect a great deal of careful investigation. However, it immediately is apparent that the nature and effect of the disruption of the phloem tissues resulting from the destruction of the cambial initials by the incipient larvae has not been considered. It is vitally important to remember that destruction of the cambial initials and the resulting disruption of its derivative tissues will have a more profound effect upon the phloem than upon the xylem due to several

factors: (1) The phloem contains many living cells in its structure, and its ability to function is governed by the continued existence of these living cells. This is in contrast to the static condition of the xylem which is composed almost entirely of dead cells which function in their role of conduction regardless of their living condition. This has been shown by many workers, Crafts et al. (1949). (2) The phloem also is a relatively short-lived tissue which is sloughed off very quickly by the development of the periderm in its outermost tissues; whereas, the comparatively great volume of xylem can function for many years, and it has a large area in which lateral translocation may take place around obstructions. These factors tend to minimize the effect of the incipient gallery in the xylem in contrast to what may be a more critical effect in the phloem tissues. Material has been collected during the past season for a histological study of the influence of the incipient gallery on the phloem tissues.

M. c.-host moisture.--It is apparent from a comparison of the mean values of sapwood and phloem moisture presented in columns 1, 3, and 8 of Table 13 that the incipient larvae of M. c. alone do not cause a significant variation in host moisture from the mean moisture condition of uninfested trees. A similar conclusion in regards to the incipient larvae in trees having both individual infestations and combination infestations with D. v. may be drawn from columns 1, 3, 8, and 9 of Table 14.

One factor of significance is that the means of sapwood or phloem moisture in trees infested with fast-growing larvae, column 2 of Table 14, do not differ significantly from the means of the sapwood or

phloem moisture of uninfested trees. These figures do not support the observation that the sapwood and phloem of these trees feel dry to the touch in contrast to the moist condition found in incipient-infested and uninfested trees. The reasons for this discrepancy are not apparent from this study.

An attempt was made in the course of these investigations to determine whether or not the internal moisture relations of the host were responsible for the inception of the fast-growing stage of the larvae of M. c. Eight Jeffrey pine logs infested with M. c. incipient larvae were secured from living trees in the Laguna Campground area. These logs varied from six to ten inches in diameter. They were taken to Camp Ole, where four of them were placed on an exposed knoll which received direct sunlight throughout the day except for the period from 11:30 a.m. to 2:30 p.m. when the area was in partial shade. The remaining four logs were placed in the shade of a group of small trees. Continuous recording thermometers were used to obtain the under-bark temperatures of one log in both of these locations.

Each week the bark was peeled from an eight-inch strip around the circumference of each log. A separate tally of the number of incipient and fast-growing larvae present on the top and bottom halves of each log was made. Sapwood and phloem moisture samples also were taken each week on each log, and an attempt was made to determine if there was a significant weekly correlation of host-moisture and under-bark temperature to the larval ratio, which was the ratio of the number of fast-growing larvae to the number of incipient larvae. These investigations, however, did not show a correlation between any combinations of these factors.

M. c.-host growth.--An analysis was made of the breast-height radial growth increment of 15 uninfested trees (see Table 15, column 1) and of 22 trees infested with M. c. or combinations of M. c. and D. v. (see Table 15, column 2). This was done in an attempt to ascertain if M. c. incipient larvae have any effect on radial growth. A comparison of the average growth indeces[4/] for these two groups of trees (see Table 15) indicates that there is no significant variation in the growth index of the infested trees from that of the uninfested trees. Hence, one may postulate that the presence of M. c. has little or no effect on the growth index of the trees. This is in contrast to the condition found by Salmon (1940) in a much more comprehensive study. He reports that trees infested with M. c. incipients show a recent suppression of their growth rate.

In all of these analyses references to the presence or absence of incipient larval stages of M. c. should be regarded critically. As noted earlier, the incidence of infestation as determined from a small blaze at breast-height is not an accurate indication of the conditions prevalent throughout the stem of the tree.

Dendroctonus valens

Even the most superficial examination of the trees in the area immediately impresses the observer with the abundance of D. v. pitch tubes at the bases of the decadent and dead trees. In some cases these attacks also are found in large numbers on apparently healthy trees. A previous investigation by DeLeon (1941) and a survey by Bongberg in 1945 have not

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4/ The growth index represents the percentage relationship of actual to normal radial growth.

Table 15.--Growth Index of Groups of Selected Infested and Uninfested Trees.

Year	(1) No D.v. (15 trees)	(2) M.c., New and old D.v. (11 trees)	(3) M.c. & New D.v. (11 trees)	(4) New D.v. (17 trees)
1949	63.7	76.2	57.6	55.1
1948	72.9	70.6	72.8	78.0
1947	89.7	97.3	80.4	92.7
1946	119.1	97.2	109.5	100.7
1945	114.4	112.2	113.6	103.7
Ave. 1945-49	92.0	90.7	86.8	86.0
1944	118.6	113.5	114.1	111.2
1943	135.0	131.2	113.4	123.6
1942	122.6	115.5	112.5	106.8
1941	102.1	117.3	99.7	106.0
1940	103.8	108.9	120.1	102.9
Ave. 1940-44	116.4	117.3	112.0	110.1
1939	90.9	100.0	113.1	117.0
1938	101.7	88.9	110.6	128.3
1937	91.1	72.6	92.0	94.9
1936	84.2	87.6	66.3	77.2
1935	70.0	91.7	77.4	69.8
Ave. 1935-39	87.6	88.2	91.9	97.4

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given any previous indication of a large D. v. population in this area. Dr. W. W. Wagener has examined the roots and stumps of many trees in the area over the past ten years, and he reports in correspondence to this office "that the present prevalence of Dendroctonus valens attacks extending underground to the root collars and roots was not formerly characteristics." However, correspondence pertaining to control activities in the area indicates that some D. v. was present in the stumps of trees killed by M. c. and Ips as early as 1938. Therefore, it may be concluded that the present increase in the size of the D. v. population from a previous endemic condition has taken place in the last one or two years.

It was postulated after examinations of many infested trees that D. v. was contributing to a great extent to the decadence of trees in the area (see Table 5). The possibility that a tree could overcome a D. v. attack seemed remote. Healthy trees were not found with old pitch tubes at their bases, which possibly would have indicated that D. v. had attacked the tree but had not affected it. Similarly, no trees were found which had been killed by M. c. alone. Therefore, it was assumed that D. v. must be playing an important part in the ultimate death of the tree. This has been substantiated to some extent by the loss occurring in 104 observation trees (see Table 5).

Previous studies.—Only a limited number of investigations have been made on the biology of this beetle in California. Struble (1928) has studied the relation of the beetle to attacks by Dendroctonus brevicomis; Bongberg (1941) and Johnson (1942) have studied its incidence in cut-over areas in northern California; and Johnson (1942a) made an intensive study of

the biology and life history of this insect in the same area. These studies have contributed very little to our understanding of the cause or effect of the insects attack in green trees. Hence, a series of studies were conducted late in the season to determine the role of D. v. in individual trees.

Biological studies.--Cox has summarized the results of his phase of this study dealing with D. v. in green trees. It is of interest to note that the results of his study concur with those obtained by Johnson (1942a) who studied attacks by this insect both in living trees and fresh stumps of ponderosa pine. The only significant difference in their observations was that Johnson found larval development taking place "while bathed in a copious flow of fresh resin." This condition never was found in trees examined in the Mt. Laguna area. In all cases the larvae did not develop successfully until the phloem no longer was functioning and the resin flow from the host tissues had subsided.

D. v.-host growth.--Growth indeces of three groups of D. v. infested trees were made and these were compared with the growth index of a similar group of uninfested trees (see Table 15). Comparisons of the average growth indeces of these four groups for the last three five-year growth periods - 1935-39, 1940-44, 1945-49 - indicate that trees attacked by D. v., when compared with uninfested trees, apparently show no variation in their growth indeces. Therefore, one may postulate that D. v. has little or no effect on the growth index of trees which it infests.

If it is at all possible, it would prove profitable to repeat this phase of the study. One must remain cognizant of the profound influence

of tree class on normal radial growth and on the ability of the various tree classes to respond to various stimuli. Therefore, such a repeat study should attempt to consider the effect of various infestation conditions on a single class of trees. This tree class preferably should be one of the more vigorous classes which are capable of showing a response to even the slightest stimulus. Another factor to be considered in such a study is the fact that midcrown radial growth shows more significant variation than does breast-height radial growth in indicating poor vigor. This relationship has been shown by Bedard (1944), and, therefore, midcrown measurements might prove to be a better indicator of the effect of infestation on radial growth than breast-height measurements.

D. v.-host moisture.--The following rather limited studies were conducted to determine the influence of D. v. attacks on the moisture relations of the host and to determine, if possible, the effect of host moisture on the attacks of the insect.

Host moisture at breast-height.--It is apparent upon examination of the mean values of sapwood and phloem moisture in Table 13, columns 4, 5, 6, 7, and 8, and Table 14, columns 4, 5, 6, 7, 8, and 9, that there is not a significant variation between the mean values of infested and uninfested trees. Apparently, the age of D. v. attacks, as indicated by the condition of the pitch tubes at the base of the trees, cannot be correlated with variations in sapwood or phloem moisture, as measured at breast-height.

Host moisture in region of attacks.--This phase of the study was initiated in the final week of the field work, and although only four trees were

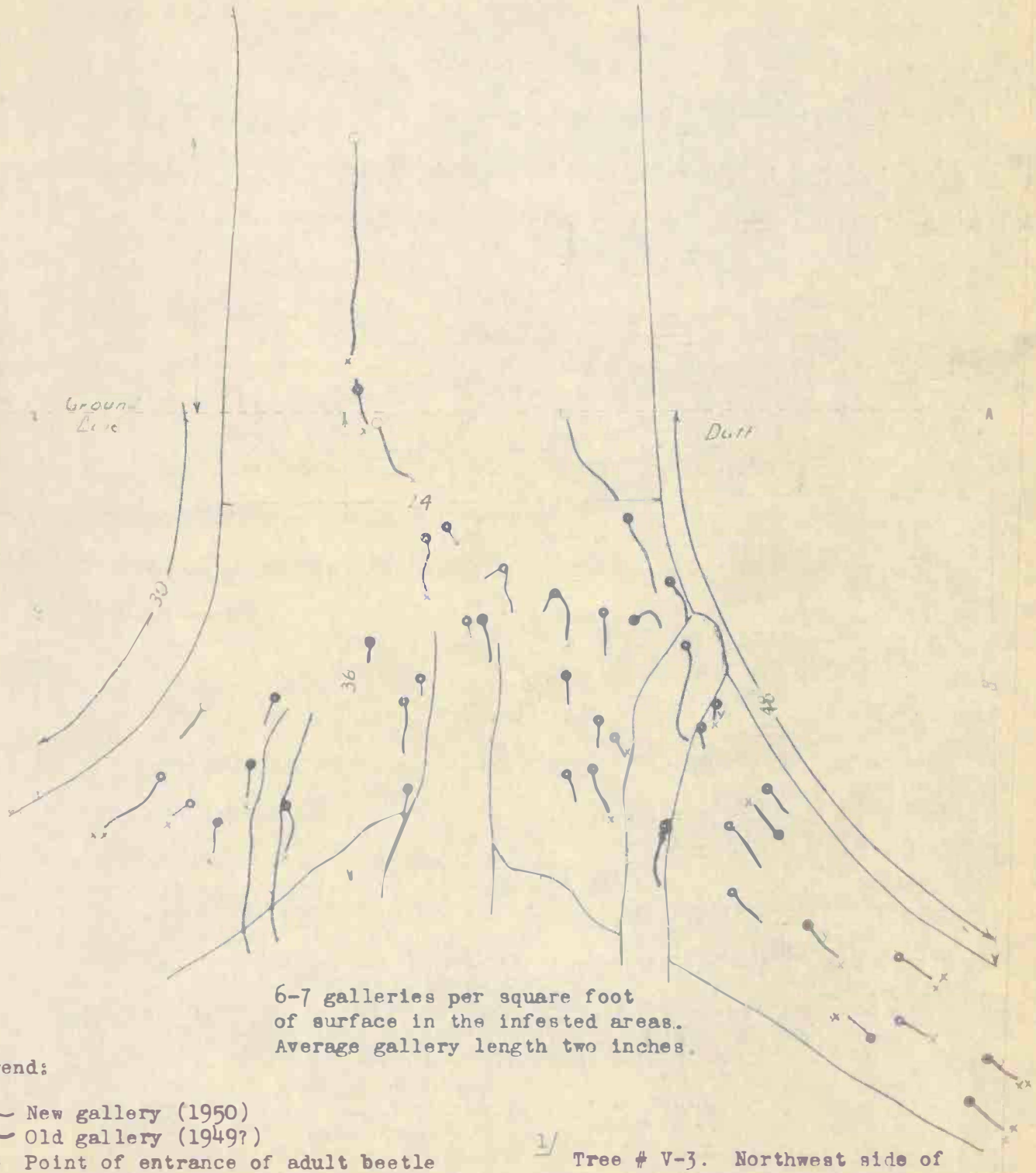
sampled and the data which was obtained was inconsistent, the writer feels that this phase of the study constitutes a profitable field for further investigation.

In the course of excavating stumps and roots of living trees and exposing the D. v. galleries therein, it was apparent that the first attacks, which were represented by the longest galleries, were made on the stem in the region of the duff layer at the surface of the soil. Later attacks, having shorter and shorter galleries, were found at greater distances from the ground line on the underground portion of the stump and on the main roots. A sketch of the pattern of attacks of D. v. adults on one side of the excavated root system of a living tree is shown in Figure 4. Johnson (1942a) previously had observed this relationship in stumps and living trees of ponderosa pine at Blacks Mountain Experimental Forest. He observed the following sequence of events in these trees:

> A period of about six weeks during which egg galleries are established above ground . . . . . disappearance of the adults from the stump above ground coincident with the development of attacks on the stump and roots below ground . . . . establishment of new attacks along the roots.

Although it was impossible to excavate a series of living trees during successive phases of new attacks, it was apparent from excavations of the root systems of five trees that this sequence of events is the prevailing condition in the stumps and roots of living trees in this area, perhaps with some modifications of the time intervals. A study of the physiological factors of the host which are associated with this downward and lateral migration would undoubtedly prove highly informative.

Figure 4.--Pattern of Attacks of Dendroctonus valens Adults on the Root System of a Living Tree 1/



6-7 galleries per square foot of surface in the infested areas. Average gallery length two inches.

Legend:

- New gallery (1950)
- Old gallery (1949?)
- Point of entrance of adult beetle
- One adult at the end of the gallery
- Eggs in gallery

1/ Tree # V-3. Northwest side of root system. Crown of tree showed typical short tufted needle clusters and some fading in the lower branches. This figure is taken directly from the original field sketch - not to scale.

A comparison was made of the phloem and sapwood moisture from various positions in the root-stump transition of four trees (see Photo 2). The results of this comparison (see Figure 5), in general, indicate an increase in sapwood moisture below the ground level and a corresponding decrease in phloem moisture below the ground level. This latter factor may bear the most significance, in that, the gallery construction of this insect takes place primarily in the phloem tissues, and the adults probably would move in the direction of a lower water concentration. This may be one of the reasons for the construction of the adult gallery in a downward direction in nearly all of the cases. However, before definite conclusions can be drawn in regard to this matter, it will be necessary to examine many more root excavations to determine the variations in the pattern of insect attack and to determine the associated variations in sapwood and phloem moisture. An analysis should also be made of the moisture conditions in uninfested trees for comparison with the values obtained from the infested trees.

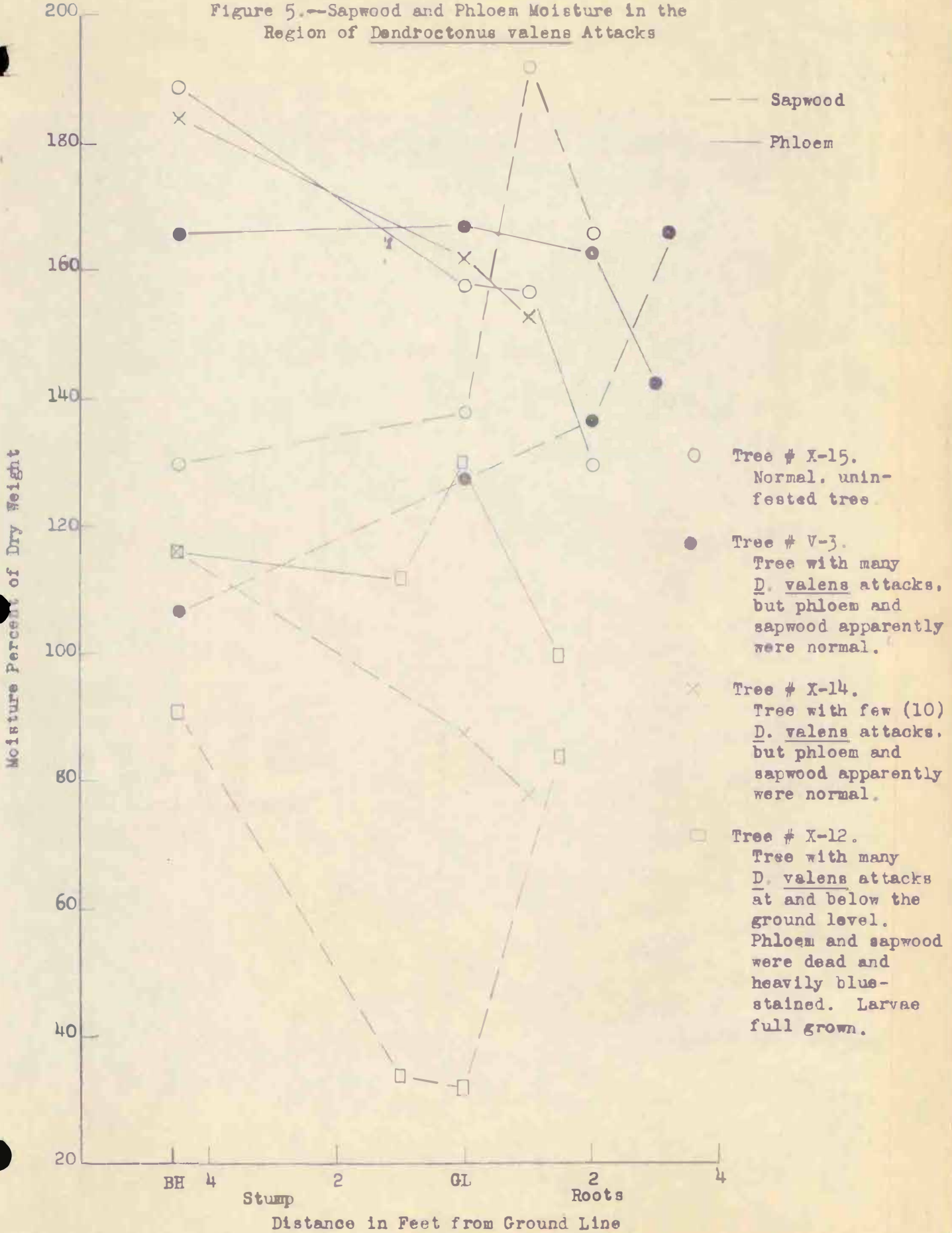
Host moisture in region of galleries.--The results of this study appear to be the most significant of all of the host-moisture relationships which were investigated. It was apparent from observing root excavations of D. v. infested trees that, as previously mentioned, larval development was not a prerequisite for tree decadence or death. If D. v. was a factor in the decadence of the trees, it seemed apparent that the adult galleries alone had to be responsible for the reduction in vigor.

A small arch punch was used to obtain a series of sapwood moisture samples in the vicinity of adult galleries of D. v. immediately after they were exposed. The moisture, as the percent of dry weight, was determined for the samples, and the values obtained were plotted in

Photo No. 2.[1/]--This photo shows the method of taking sapwood moisture samples with a large arch punch in the region of root-stem transition. Sample taken was at the ground line. Another sample can be seen on the root at the right of the photo. The root system of this tree was excavated to determine the extent of Dendroctonus valens attacks on an apparently healthy tree. The excavated regions of this tree were found to be completely blue-stained and non-functional.

[1/] Photo taken by David Cox.

Figure 5.--Sapwood and Phloem Moisture in the Region of Dendroctonus valens Attacks



their respective positions on diagrams of the exposed galleries (see Figures 6a, 6b, 6c). This study was initiated at the close of the season; therefore, it was impossible to sample as large a series of galleries as would have been desirable. The results obtained, however, do indicate the effect of the adult gallery in drying out the sapwood directly beneath the gallery.

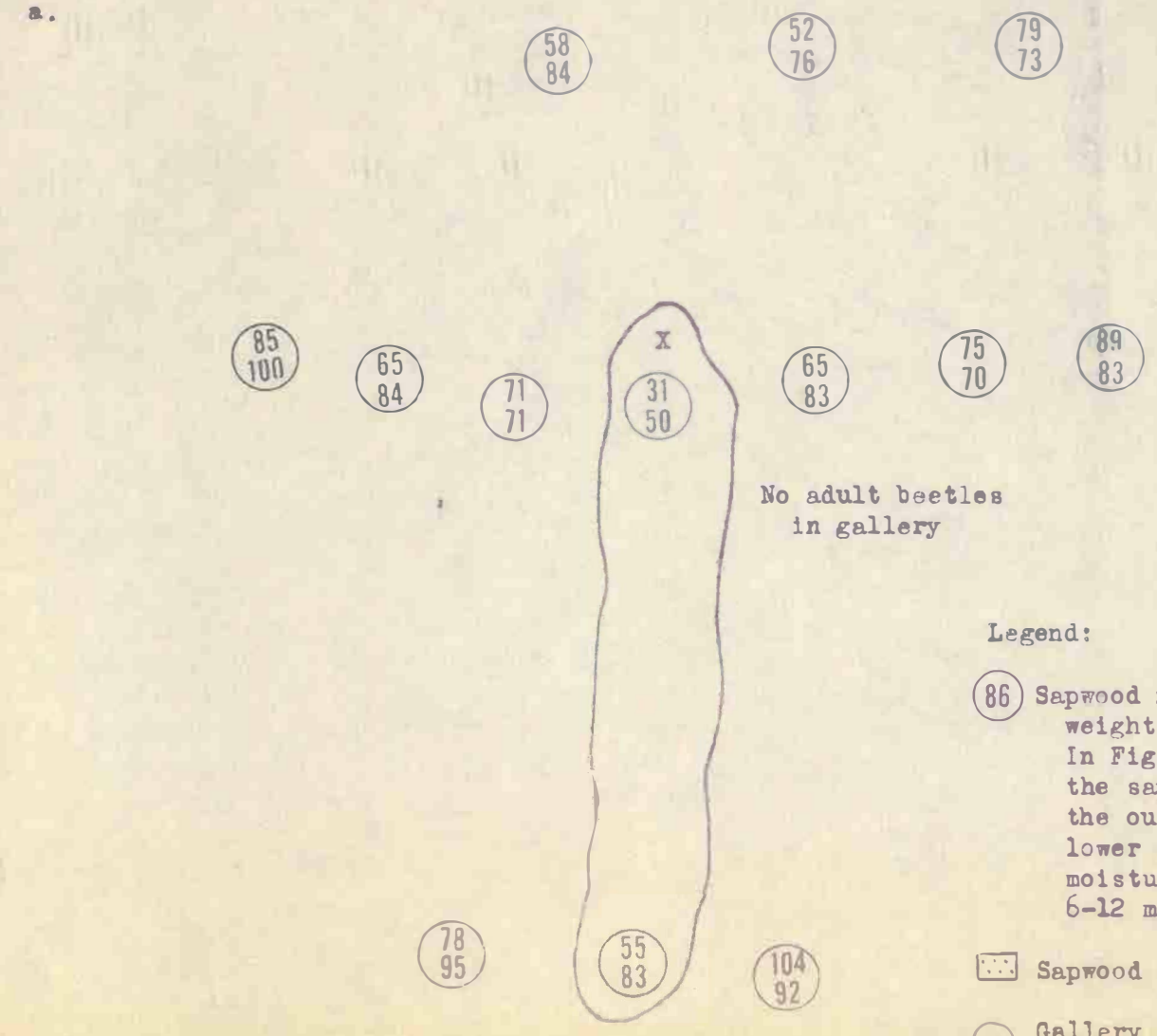
One factor noted in the excavations was the frequent occurrence of areas of sapwood adjacent to the adult galleries which showed varying degrees of "resining" or concentrations of extractives (Figure 6b). The nature of the formation of these areas is unknown although they have been found to be associated with wounds of various types.

Dr. A. B. Anderson of the faculty of the School of Forestry, University of California, has stated in personal conversation that the extractives, which are not water-soluble, probably displace any water present in these areas and by virtue of this impregnation with extractives or resin the affected areas would no longer function in water and solute conduction. This is confirmed to some extent in his analyses by the lower moisture content in these areas of extractive concentration as compared with the moisture content of the surrounding normal tissues. However, the significance of the role of these impregnated areas in stopping conduction is not known, and further investigations into the frequency of their occurrence and their effect on the sapwood should be undertaken.

Vertical Extent of drying under galleries.--It is impossible to draw positive conclusions on this matter from the gallery samples depicted in Figures 6a, and 6b; however, additional studies should be undertaken to show the vertical extent of the drying by taking a series of samples

Figure 6.--Sapwood Moisture in the Vicinity of
Dendroctonus valens Adult Galleries

a.



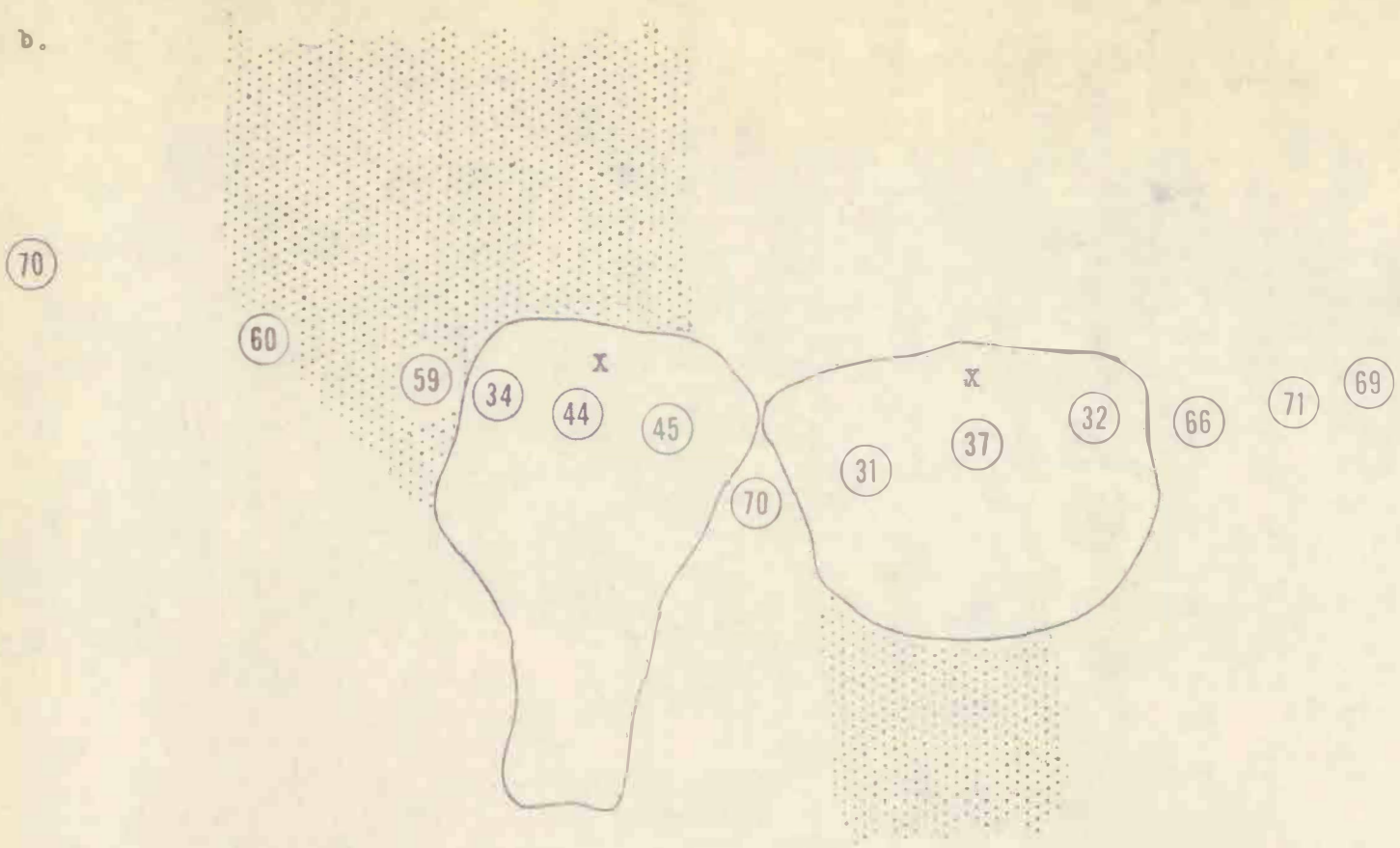
Legend:

(86) Sapwood moisture (percent of dry weight) at the point of sampling. In Fig. 6a the upper number is the sapwood moisture value for the outer 6 mm. of sapwood; the lower number is the sapwood moisture value for the inner 6-12 mm. of sapwood.

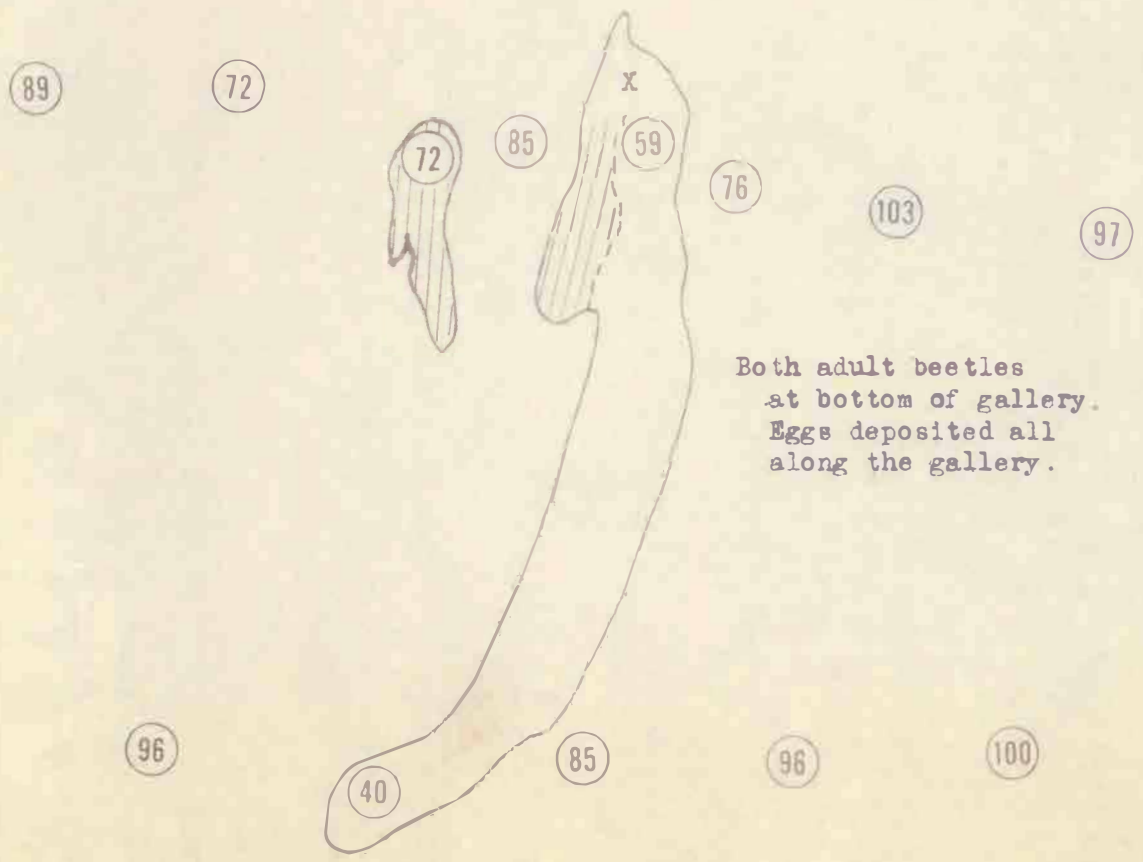
Sapwood "Resining"

Gallery boundaries. "X" denotes gallery entrance. denotes an old gallery adjacent to the new gallery.

b.



c.



upward along the grain from the top of the gallery. This might give an indication of the rapidity with which water diffuses laterally into the areas above the galleries. A similar study should be made of the vertical drying of the sapwood above galleries which extend diagonally across the grain of the wood. It may be possible that these latter galleries, which are relatively infrequent in occurrence, have a more profound drying effect on the sapwood than do the galleries which follow the grain more closely.

Lateral extent of drying under galleries.—The samples taken around the galleries depicted in Figures 6a, 6b, and 6c, all show the restriction of the sapwood drying to the exact edge of the gallery itself. The most striking example of this is shown in Figure 6b, in which the two galleries were in contact with each other at only a single point. Yet immediately below the point of contact in an area just large enough for a single sample, the sapwood moisture was identical to that observed in the uninfested normal parts of the same root. As noted in the preceding section, it would be desirable to determine the lateral extent of drying of the tissues adjacent to galleries extending across the grain.

Radial extent of drying under galleries.--Only one excavation was sampled to study this relationship, but the results obtained, which are insignificant by themselves, do indicate an agreement with the findings of other workers. Caird (1931), using small trees cut at various periods after Dendroctonus frontalis attack, has shown by stepping the trees in dye solution that the air from the adult galleries moves radially inward into the sapwood and that this air interrupts conduction progressively inward in successive annual rings. He also reported that the normally non-functioning inner rings commence to conduct water when the outer

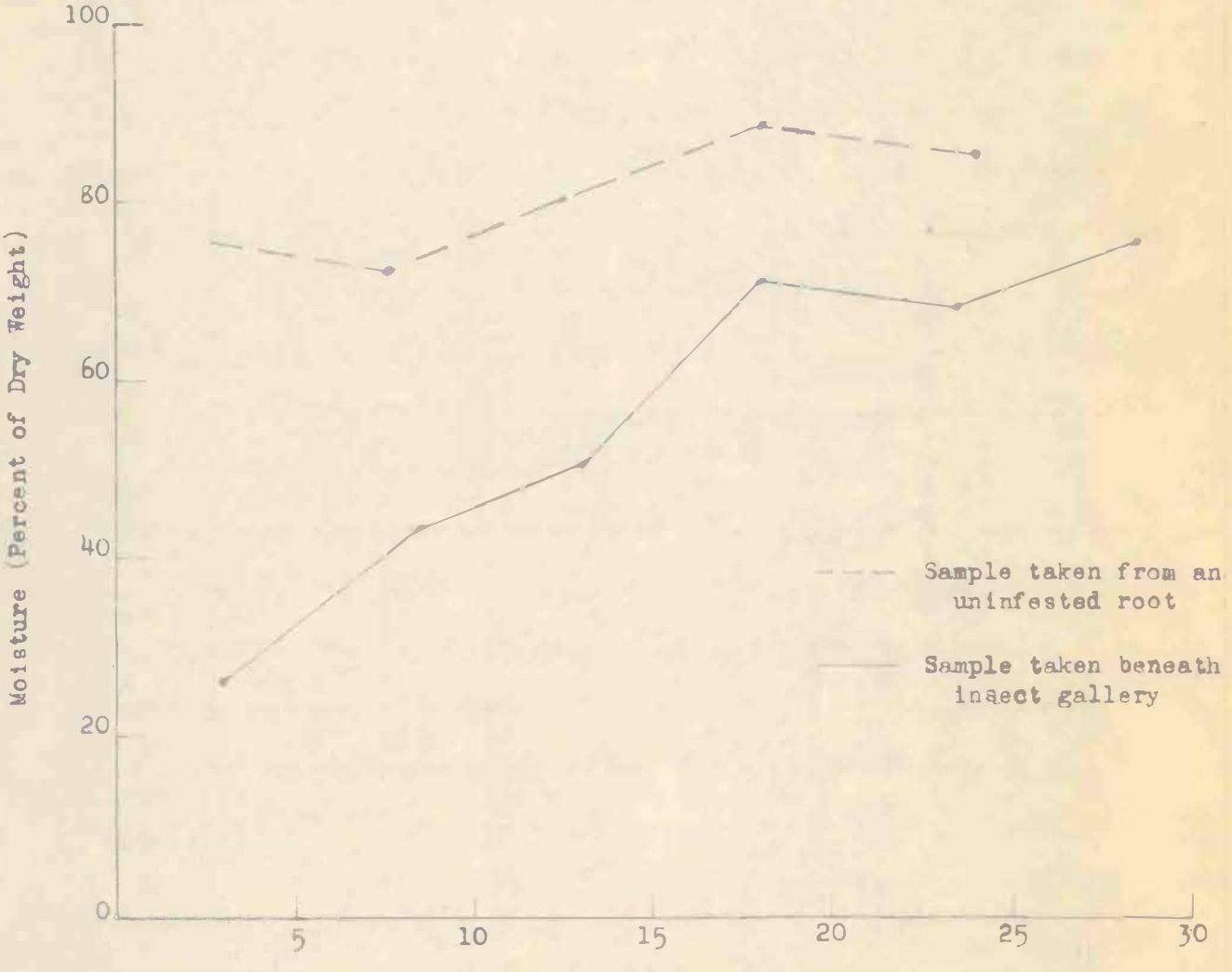
rings were dried out. Hence, the conduction of water was maintained past these areas of surface drying. Although his observations of this drying effect were made in areas of extensive gallery development, he did not investigate the drying effects of a single gallery.

It seems entirely logical to assume that the individual D. v. galleries would show similar effects upon the sapwood as did the mass of galleries in Caird's investigations. The one excavation shown in Figure 6b, which was sampled for this information, gives support to this assumption, in that, the more pronounced drying in the outer rings beneath the gallery is significantly different from the condition in the normal sapwood as shown in Figure 7. The values of sapwood moisture in Figure 6a also show that there is a more pronounced drying of the outer 6 mm. of sapwood directly beneath the gallery.

It is obvious that more work needs to be done on this phase of the host moisture. One particular subject requiring investigation is the question of how many of the sapwood rings function in the conduction of solutes and water to the crown. Without knowledge of the conduction capacity of the sten, the effect of radial drying beneath the adult gallery can not be fully appreciated.

D. v.-host phloem.--Another factor for future consideration is the need for an investigation of the effect of the adult gallery on the phloem tissues of the host. From superficial observations of many galleries which were exposed, it did not appear that the phloem immediately adjacent to the galleries was affected in any manner by either new or year-old galleries. It may be, as with other bark beetles, that larval development is dependent upon the breakdown of phloem tissues or their components by

Figure 7.--Radial Extent of Drying Under a *Dendroctonus valens* Adult Gallery 1/



1/ The values used in this figure were obtained from the gallery depicted in Figure 6b.

the action of various microorganisms. Thus, the mechanical removal of the phloem tissues in gallery construction without the subsequent breakdown of adjacent phloem tissues by various agents may have little or no influence on the tree itself and may make it impossible for larvae to develop.

D. v.-blue-staining fungi.--In the course of excavating D. v. infested stumps, it was noted that blue-staining had taken place in the sapwood in all areas in which larval development had been successful. Only occasionally was blue-stain found in association with adult galleries which had not resulting in successful larval development. In all cases in which this latter association was encountered the gallery was in the stump of a tree in which successful larval development had taken place in some other portion of the stump. It is possible that a successful attack, as determined by successful larval development, may be dependent upon the ability of the blue-stain organisms, which are introduced into the host by the adults, to develop and in some way alter the host so that larval development may take place.

To the author's knowledge there are only three references in the literature to studies conducted in this country which have probed the interrelationships of bark beetles and blue-staining organisms. Nelson and Beal (1929), Nelson (1934), and Caird (1934) conducted their studies with the southern pine beetle, D. frontalis, and Ceratostomella species on young southern pines. They came to various different conclusions. Caird concluded that the "action of fungi might in itself account for the death of the tree. Although it seems these various factors are interpendent . . . Ceratostomella may penetrate the wood to the ninth or tenth rings and not be apparent to the eye . . . The loss of moisture

and the positions of the fungi are intimately connected . . . Drying of the wood may occur without the immediate presence of any fungus."

From these three studies it is possible to conclude that the position of fungal mycelia in the sapwood is correlated with a loss of moisture. However, the drying action of the adult galleries is sufficient to give a similar loss of moisture without the presence of any fungus. It also is of interest to note that blue-stain only developed when introduced by the adult beetles and seems to have what might be termed a "symbiotic" relationship with the insects. Apparently blue-stain cannot develop under normal sapwood moisture conditions. However, the initial and continued drying beneath the adult gallery, resulting from exposure of the sapwood to the air in the gallery, may be sufficient to allow the blue-stain organisms to develop successfully.

The possibility of a symbiotic D. v.-blue-stain relationship only was investigated to a limited extent during the past season. Several petri dish cultures were made on crude pine-malt and water-malt agar. Adult beetles, frass, and sapwood and phloem tissues adjacent to the galleries were cultured; however, the crude sterilization and inoculation techniques which were used made it impossible to draw any conclusions from these plates. With the proper facilities and techniques this host-fungus-insect relationship could be studied, and such an investigation would be a major contribution to the knowledge of the role of this insect in tree decadence and death.

SUMMARY OF CONCLUSIONS

Although many of the studies discussed in this report have not been completed, it seems valid to draw several preliminary conclusions at this time.

1. Melanophila californica, Ips oregoni and Dendroctonus valens apparently are the only primary forest insects infesting Jeffrey pine in this area.

2. The most commonly encountered pattern of infestation in Jeffrey pine is a combined attack by D. valens and M. californica resulting in a typical condition of tree decadence characterized by short, tufted, needle clusters at the tips of the branches, and the fading of the needles on the lower branches.

3. Jeffrey pines infested primarily with I. oregoni show a typical uniform, rapid fade of the needles in the infested portion of the crown. From the type of group killing caused by this insect, it is apparent that succeeding generations of Ips move from tree to tree within a group rather than move away from the group in which they originate to establish new kills.

4. It is obvious that the annual deviations from the normal radial growth pattern are not significantly correlated with seasonal deviations from the normal precipitation. This lack of correlation may be the result of the small number of trees which were sampled, or it may indicate that tree growth is not as dependent upon the precipitation in this area as it is in other areas. It is apparent from other correlation analyses, however, that two- or three-year cumulative departures of precipitation show significant correlations to annual growth departures and, therefore, that trees in this area are more dependent on the precipitation of

several seasons than on the precipitation of the current season.

5. It is obvious that the most prolonged period of drought, or, at least, subnormal precipitation conditions, in the past 50 years has prevailed in this area since 1945. From these studies it also seems apparent that neither growth nor rainfall show any cyclic pattern during the past 50 years; therefore, it is probable that nothing more than chance variation in rainfall may be expected in the seasons which are to follow.

6. It seems impossible to correlate the various periods of high or low precipitation with the incidence of any of the biological agents which have played an important part in the decadence or death of trees in the past. However, it seems possible that the high incidence of Fomes annosus in the early 1940's was correlated with the excessive moisture of that period, and the present abundance of D. valens and absence of Fomes annosus may be correlated with current drought conditions.

7. It has been impossible to show a correlation between the various crown conditions of the trees and the corresponding sapwood and phloem moisture. Similarly, the presence of one or more entomological agents has not been shown to result in a significant deviation of the means of sapwood or phloem moisture from the means of moisture found in uninfested trees.

8. M. californica has not been found to be capable of killing a tree independent of the attacks of other insects, and in this regard the fast-growing larval stage of this insect has not been found to develop until the phloem of the infested tree is non-functional and dry to the touch.

9. There is some indication from a limited sample that M. californica and D. valens show no preferential selection of trees which have different shapes of crowns, or densities of crowns, or both.

10. Investigations show that D. valens and M. californica could be found in all stages of development in trees of all age and crown classes, on all sites, and at nearly any period during the growing season of the host; therefore, it is surmised that the periodicity of their attacks apparently are not correlated with the internal seasonal growth processes of the hosts.

11. After comparing the growth indeces of trees infested with M. californica or D. valens, or both, with the growth index of uninfested trees, it is postulated that these insects have little or no effect on the growth rate of the infested trees.

12. From the lack of reference to D. valens in previous investigations in this area, it is assumed that the present increase in the size of the D. valens population from previous low levels has taken place in the last one or two years.

13. It is postulated that D. valens by its' pattern of attack in this area is responsible for much of the decadence of the trees in the stand. However, it is possible that the attacks of these beetles merely serve as indicators of decadence and that their attacks do not play a major role in the actual decline of the trees. Observations of trees attacked by various numbers of D. valens adults indicate that the greatest part of the loss attributable to this insect occurs in trees attacked by many adults, as would be expected. This may further indicate that D. valens is actually responsible for tree death, and that

its' attacks do not merely indicate approaching death.

14. The results of investigations of a series of D. valens galleries have shown that successful larval development of this insect is not a prerequisite for tree death, and, therefore, if this beetle contributes to the decadence of the trees, it seems apparent that the adult galleries alone have to be responsible for the reduction in vigor.

15. Investigations of the effect of the galleries of D. valens on the moisture relations of the host have been conducted to determine the role of this beetle in tree decadence. These investigations indicate that:

a. Sapwood or phloem moisture at breast-height shows no significant differences in D. valens infested and uninfested trees.

b. In general, sapwood moisture increases and phloem moisture decreases as samples are taken progressively downward from the ground level and laterally along the main roots of infested trees.

c. Adult galleries have a profound drying effect on the sapwood directly beneath the gallery. The radial depth of drying probably varies with the age of the gallery. The tangential extent of drying beneath the gallery is restricted precisely to the edge of the gallery. The vertical drying effect beyond the limits of the gallery is not indicated by the samples discussed in this study.

BIBLIOGRAPHY

Antevs, E. 1938. Rainfall and Tree Growth in the Great Basin. American Geographical Society. Special Publication No. 21.

Baker, H. and W. O. James. 1933. The Behavior of Dyes in the Transpiration Stream of Sycamores (Acer pseudo-platanus). New Phytologist 32:245-260.

Beal, J. A. 1930. Phloem Moisture and Beetle Susceptibility of Western Yellow Pine. Station Report. Portland, Oregon.

Bedard, W. D. 1941. Results of Preliminary Studies Concerning the Condition of Beetle Susceptible Ponderosa Pines. Station Report. Portland, Oregon.

_____. 1944. The Effect of Certain Soil and Injury Treatments on the Growth of Ponderosa Pine. Station Report. Berkeley, Calif.

Bongberg, J. W. 1941. Effect of Red Turpentine Beetle Attacks on Cutover Areas in Providing Green Trees More Susceptible to Primary Bark Beetles. Station Report. Berkeley, Calif.

Caird, R. W. 1931. Physiology of Trees Attacked by Bark Beetles and Their Associated Fungi. Station Report. Asheville, N. C.

_____. 1934. Physiology of Pines Infested with Bark Beetles. Bot. Gaz. 96:709-733.

Cox, David. 1951. A Study of the Biological Causal Agents of Jeffrey Pine Mortality, Laguna Mountain Recreational Area, Cleveland National Forest, Season of 1950. Station Report. Berkeley, Calif.

Crafts, A. S., H. B. Carrier, and G. R. Stocking. 1949. Water in the Physiology of Plants. Waltham, Mass.

Craighead, F. C. 1941. The Effect of Drought on White Pine. Jour. For. 39:618-619.

DeLeon, D. 1941. Some Biological Considerations of the 1940-1941 Mt. Laguna Recreational Area Control Job. Station Report. Berkeley, Calif.

Douglass, A. E. 1928. Climatic Cycles and Tree-growth. Carnegie Institute of Washington. Publ. No. 289, vol. 2.

_____. 1933. Tree Growth and Climatic Cycles. The Scientific Monthly. 37:481-495.

Douglass, A. E. 1936. Climatic Cycles and Tree Growth. A Study of Cycles. Carnegie Institute of Washington. Publ. No. 289, vol. 3.

Hall, R. C. 1949. An Ecological Study of Ips confusus in Northern California. Progress Report - Seasons of 1947 and 1948. Berkeley, California.

Hawley, Florence. 1941. Tree Ring Analysis and Dating in the Mississippi Drainage. The University of Chicago Publications in Anthropology, Occasional Papers No. 2.

Johnson, J. W. 1942. Causes and Effects of Dendroctonus valens Attacks on Reserve Trees in Areas Treated by Sanitation-Salvage Methods in Providing Trees More Susceptible to Primary Bark Beetles. Station Report. Berkeley, California.

_____. 1942a. Observations on the Biology of Dendroctonus valens LeConte, Blacks Mountain Experimental Forest, Seasons of 1941. Station Report. Berkeley, California.

Keen, F. P. 1937. Climatic Cycles in Eastern Oregon as Indicated by Tree Rings. Monthly Weather Review, 65:175-188.

_____. 1941. Variance of Growth Rate for Index Trees. Station Report. Portland, Oregon.

MacDougall, D. T., J. B. Overton, and G. B. Smith. 1929. The Hydrostatic-Pneumatic System of Certain Trees: Movements of Liquids and Gases. Carnegie Institute of Washington. Publ. No. 397:1-99.

Miller, J. M. and F. P. Keen. 1945. Biology and Control of the Western Pine Beetle. Station Report. Berkeley, California.

Nelson, R. M. 1934. Effect of Blue-stain Fungi on Southern Pines Attacked by Bark Beetles. Phytopath. Zeitschr. 7:327-353.

_____ and J. A. Beal. 1929. Experiments with Blue-stain Fungi in Southern Pines. Phytopath. 19:1101-1106.

Priestly, J. H. 1935. Sap Ascent in the Tree. Science Progress. 30:42-56.

Salman, K. A. 1940. A Preliminary Study of the Diameter Growth of Ponderosa Pine and Some of its Relations with Risk and Incipient Infestations of the Flathead Borer (Melanophila californica Van Dyke). Station Report. Berkeley, California.

Salman, K. A. and J. W. Johnson. 1940. Studies on the Movement of Solutions Through Flathead Caused Scars in the Sapwood of Ponderosa Pine. Station Report. Berkeley, California.

Schantz-Hansen, T. and P. N. Joranson. 1939. Some Effects of the 1936 Drought on the Forest at the Cloquet Forest Experiment Station. Jour. For. 37:635-639.

Struble, G. S. 1928. A Preliminary Study of the Life History and Habits of the Red Turpentine Beetle in Western Yellow Pine. Station Report. Stanford University, California.

_____. 1947. A Study of Factors in the Development of Ips Outbreaks. Progress Report of Sierra Studies, 1946. Station Report. Berkeley, California.

_____. 1949. A Study of Factors in the Development of Ips Outbreaks. Progress Report of Southern Sierra Studies, Season of 1948. Station Report. Berkeley, California.

West, G. S. Jr. 1937. The Nature of Galleries Formed by Incipient Stage Larvae of Melanophila californica, Van Dyke in Ponderosa Pine. Station Report. Berkeley, California.

_____. 1947. The California Flatheaded Borer (Melanophila californica, Van Dyke) in Ponderosa Pine Stands of Northeastern California. Canadian Jour. of Research, D, 25:97-118.